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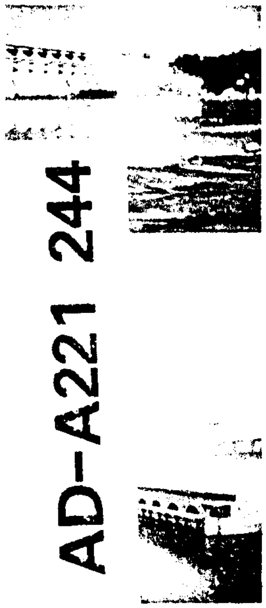
WORKSHOP PROCEEDINGS: RESULTS OF THE RICHARD B. RUSSELL FISH ENTRAINMENT STUDY



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John M. Nestler, Gene R. Ploskey, Editors

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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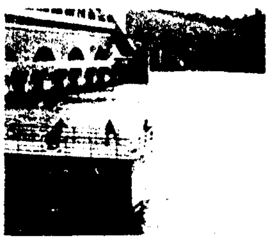

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This report documents technical presentations made during a workshop on the Richard B. Russell (RBR) Fish Entrainment Study (RBRFES) at Savannah, GA, January 1989. Workshop presentations cover data collected from February 1986 through September 1988. Presentations documented the assessment phase of the study in which the potential for entrainment and subsequent mortality of fish in turbines of the RBR Dam were evaluated for proposed pumped-storage operations. The workshop presented information in three general areas. Session I concentrated on general information describing the J. Strom Thurmond (JST) Lake fishery and compared fish compositions and abundances in the tailwater with those in other portions of JST Lake on a seasonal and annual basis. Session II presentations focused on detailing information on the fishery in the tailwater of RBR Dam. Session III featured associated studies or recently planned or newly completed work to address issues and problems arising since the RBRFES was begun.

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PREFACE

The proceedings reported herein documents technical presentations made during a workshop on the Richard B. Russell Fish Entrainment Study (RBRFES) at Savannah, GA, on 18-19 January 1989. The workshop presented data collected and analyzed from the study from February 1986 through September 1988. The study was sponsored by the US Army Engineer District, Savannah (SAS), under Intra-Army Reimbursable Services Order No. EN-BC 86-27, dated 27 January 1986 and managed by the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. Dr. John M. Nestler is the Principal Investigator of the Richard B. Russell Fish Entrainment Study. Mr. Mark McKewitt, SAS, managed the RBRFES.

The workshop was organized jointly by the SAS and the WES. The workshop presentations were compiled by Dr. Nestler and Mr. Gene R. Ploskey of the Water Quality Modeling Group (WQMG), Ecosystem Research and Simulation Division (ERSD), EL, WES. This report was prepared under the direct supervision of Dr. Nestler and under the general supervision of Mr. Mark Dortch, Chief, WQMG; Mr. Donald L. Robey, Chief, ERSD; and Dr. John Harrison, Chief, EL. Dr. Thomas Wright and Mr. Tom Cole provided technical reviews. This report was edited by Ms. Lee T. Byrne of the WES Information Technology Laboratory.

The Commander and Director of WES during the publication of this report was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02832	cubic metres
degrees (angle)	0.01745	radian degrees
feet	0.30480	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

WORKSHOP PROCEEDINGS: RESULTS OF THE RICHARD B. RUSSELL FISH ENTRAINMENT STUDY

INTRODUCTION

John Nestler

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This report documents the results of a workshop held on 17 January 1989 at Savannah, GA. In this workshop, results from the Richard B. Russell Fish Entrainment Study (RBRFES) from February 1986 through September 1988 were presented to representatives of the US Army Engineer District, Savannah (SAS); US Fish and Wildlife Service (FWS); Georgia Department of Natural Resources (DNR); South Carolina Wildlife and Marine Resources Department; US Army Engineer Division (USAED), South Atlantic; and the FWS Atlanta Regional Office.

This is the second of two workshops based on the RBRFES. The first workshop was held in Hickory Knob State Park, South Carolina, May 1987, and is documented in Nestler (in preparation).* The preliminary results and interpretations of the first workshop proceedings are superceded by these proceedings.

A workshop format was employed to transfer data and results from the Fish Entrainment Study both to decision makers within the SAS and to other workshop participants for four reasons. First, a workshop allows the most timely presentation of study results because the lengthy report preparation process is avoided. Thus, the information can be disseminated and responses received in a time frame consistent with the requirements of the power-on-line schedule. Second, the shortened preparation time required for a workshop allows more recent data to be analyzed and presented. Third, the workshop format provides an opportunity for workshop participants to directly query the technical staff that collected and analyzed the data. Technical questions can

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* John M. Nestler, "Preliminary Results of the Richard B. Russell Fish Entrainment Study," Miscellaneous Paper (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

be discussed at the workshop by scientists and technicians involved in the study. Fourth, and perhaps most importantly, the workshop served as a forum for representatives of the resource agencies to discuss their impressions and interpretations of the data and to pass their recommendations regarding pumped storage at Richard B. Russell (RBR) directly to the decision makers of SAS.

These proceedings, like the workshop, are organized into three major sections. The workshop was prefaced by two presentations, "RBR Structural and Hydraulic Description" by Mr. Mike Schneider and "Temporal and Spatial Water Quality Patterns" by Mr. Joe Carroll. These presentations provided background information required for the rest of the workshop but are not part of the RBRFES and, as such, are not documented in these proceedings.

The first workshop session, "Description of J. Strom Thurmond (JST) Lake Fishery and Comparative Assessment of Temporal and Spatial Distributions of Fish," presented information of a general nature to serve as a backdrop for detailed studies conducted in the immediate vicinity of Richard B. Russell Dam. In general, descriptions of sampling gears were made during the first session and were not repeated in related presentations in later sessions. Most notably, general information concerning hydroacoustics sampling was restricted to the first session and was not repeated in the later sessions. Consequently, the reader of these proceedings should consult the presentation, "Lakewide Hydroacoustic and Thurmond Lake-Russell Tailwater Comparisons" by Dr. Schreiner, for background and supportive information potentially required for the later hydroacoustics presentations. The second session, "J. Strom Thurmond Tailwater Investigations," addressed questions and issues concentrating on the tailwater of Richard B. Russell Dam. In the third session, "Associated Study Efforts," supportive information and information from parallel studies conducted concurrently with the RBRFES were presented. A presentation by Stone and Webster Engineering Corps is not included in these proceedings, but the same information can be found in a 60-percent design-feature memorandum on a fish protection system for RBR drafted by Stone and Webster Engineering Corp in 1989 and available from the SAS.

Several conventions were employed throughout the presentations. The term "tailrace" refers to the riprapped portion of the Savannah River arm of JST and is equivalent to Station 1. The tailrace extends from the foot of RBR Dam downstream for a distance of 450 m. "Tailwater" refers to the entire Savannah River arm of JST extending from the downstream end of the tailrace to

the confluence with the Broad River (a distance of approximately 8 km). Tributary stations were located in the three major tributaries of JST.

Background

The SAS develops and manages water resources on the Savannah River. The RBR Dam and Lake, begun in 1976, is the most recent of the Savannah River impoundments. The RBR project is located on the Savannah River between Hartwell Lake (HL) to the northwest and JST Lake (formerly Clarks Hill Lake) to the southeast and forms part of the boundary of the States of Georgia and South Carolina.

Completion of the generating facilities at RBR will significantly add to the generating capacity of the Savannah River system. Presently, hydroelectric power is generated by four 75 mW conventional hydroelectric units. Current plans provide for four additional pump-turbine units that will generate power during peak load periods.

Experience at other hydropower projects, both conventional and pumped-storage projects, in which an upstream project discharges into the headwaters of a downstream reservoir, indicates that the major effects of operation are experienced by the downstream reservoir. Pumped-storage operation caused significant mortality of fish at Harry S. Truman Dam (HST) in Missouri. Mortality is a function of differences in the distribution and abundance of fish between the forebay and afterbay. During generation, water is released from deep in the upstream reservoir where the density of fish is generally low. Therefore, fish mortality during generation is generally negligible in turbines of large hydropower storage projects. However, during pumped-storage operation, water is pumped back from a shallow and narrow part of the downstream reservoir where the concentration of fish can, at times, be high. This problem is most pronounced in tandem projects when blockage of spawning migrations by the upstream project may cause high, springtime concentrations of fish in the vicinity of the powerhouse.

J. Strom Thurmond Lake, immediately downstream of RBR, has an established fishery managed by the States of Georgia and South Carolina. A partial list of species important to the JST fishery includes striped bass, white bass, crappie, several species of sunfish, sauger, white catfish, channel catfish, bullhead, hybrid bass, largemouth bass, yellow perch, gizzard shad,

blueback herring, threadfin shad, walleye, and flathead catfish. The States of Georgia and South Carolina, the US Fish and Wildlife Service, and the SAS have all expressed their concern about mortality of entrained fish during pumpback at RBR.

The RBRFES

The SAS is sponsoring the RBRFES to collect information that can be used to avoid, or at least minimize, problems similar to those experienced at HST. This study is designed to provide information to allow the SAS to make the best decisions regarding pumped-storage operation at RBR, that is, to provide data to optimize pumped-storage operation with minimal negative impact on the JST Lake fishery.

Objectives of the RBRFES are to:

a. Determine the potential for fish mortality during pumped-storage operation (identify species and numbers of fish in jeopardy).

b. Relate the significance of mortality to the total JST fishery (relate the number of fish in jeopardy to estimates of the total number of fish in JST).

c. Relate the abundance and distribution of fish in the tailwater to project operation, water quality, season, and reservoir hydrodynamics. This information can be used to assess operational criteria for minimizing detrimental effects on the JST fishery.

d. Identify and evaluate behavioral barriers for managing fish distributions in the immediate tailwater.

The following presentations feature objectives a through c. At the time of the workshop, the RBRFES was beginning to address Objective d.

Acknowledgments

The editors acknowledge contributions of Dr. Jim Pennington, formerly of the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), and Messrs. Richard Coleman, formerly of Aquatic Habitat Group (AHG), EL, and Richard L. Kasul of AHG. These individuals assisted in the early design of the RBRFES. In addition, Messrs. Coleman and Kasul were responsible for collecting and processing hydroacoustics data for the study. Mr. Kasul analyzed some of the hydroacoustics data presented in Session I. Mr. Ray Vandenberg of the USAED, Kansas City, assisted in the early design of this study and related experierces of the USAED, Kansas City, with the HST

pumped-storage project. Mr. Steve Walker, formerly of the Water Quality Modeling Group (WQMG), EL, developed computer programs that created many of the figures on fish distributions and hydroacoustics.

SESSION I: DESCRIPTION OF J. STROM THURMOND FISHERY AND COMPARATIVE ASSESSMENT OF TEMPORAL AND SPATIAL DISTRIBUTION OF FISH

CHARACTERISTICS OF THE FISH COMMUNITY OF J. STROM THURMOND RESERVOIR AND A DESCRIPTION OF TEMPORAL AND SPATIAL DISTRIBUTIONS

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Introduction

Quantitative samples of the JST fish community have been collected since February 1986 to determine species composition and to evaluate relationships between the abundance and species present in the RBR tailwaters and the remainder of the reservoir. Questions addressed specifically in this section include:

a. What are the principal components of the fish community?

b. How does the community vary within the reservoir (tributaries, main lake, and tailwaters)?

c. What are the seasonal trends in composition and abundance in major areas of the reservoir?

d. Is the tailwater area unique?

Methods

Three sampling methods have been used to characterize the fish community. Gill netting was conducted from February 1986 through September 1988 at 11 stations (Figure 1): three tailwater sites (Stations 1-3), four tributary sites (Stations 4, 5, 6, and 11), four main lake sites (Stations 7-10). Each sampling effort at Stations 2-11 consisted of overnight sets of four 45.72-m experimental gill nets that had six 7.62-m panels of monofilament webbing ranging from 25.4- to 88.9-mm bar measure. Only two nets were used at Station 1 because of concern over high catch rates. Gill netting is most effective for sampling species of fish that are active and vulnerable to entanglement in the net mesh sizes used. The data are summarized according

to the biomass of each species caught per net (i.e., kilograms per net).

Electrofishing was conducted from July 1986 through September 1988 at the same 11 stations used for gill netting. Electrofishing at Stations 2-11 consisted of sampling three permanently located 152.4-m transects that were randomly selected at the beginning of the study. However, at the tailrace (Station 1), sampling was confined to three 305-m transects--one along the South Carolina bank, one along the Georgia bank, and one along the dam face. Electrofishing is most effective for fish that occur in shallow water along the shore. The data are presented as kilograms per hour by species.

Cove rotenone samples were collected in the summers of 1986 and 1987. Four coves were sampled in 1986, and a fifth was added in 1987 (Figure 2). Sample sites were selected to facilitate comparisons with available historic data and to provide a broad coverage of the reservoir. For each sample, a block net was placed across the mouth of the cove, rotenone was applied, and dead fish were picked up for 2 days. This procedure provides estimates of the biomass of each species present, expressed as kilograms per hectare.

Principal Components of the Fish Community

Cove rotenone

Total fish biomass varied considerably among coves and between years for the same coves (Figure 2). The five species that ranked highest in biomass were the same in both years: bluegill, gizzard shad, common carp, largemouth bass, and redear sunfish (Figure 3). Long-term trends of biomass were evaluated for three coves sampled by the Georgia DNR prior to 1986 (Figure 4). In general, biomass determined in 1986 and 1987 exceeded that measured in 1976-1985. The extremely high biomass at the Buoy 140 site in 1986 reflected the unusually high abundance of common carp and flathead catfish that year. Cliatt Creek was not sampled in 1986 because of low water levels.

Gill netting

Total biomass of the 15 most commonly collected species is summarized in Figure 5 for 1986-1988.

Electrofishing

Total biomass of the 15 most commonly collected species is shown in Figure 6 for 1986-1988.

Among-gear variation

Species composition varies among gear types because of gear selectivity, activity levels, and inshore-offshore distributions that vary among species.

Spatial Variation

Catches of 7 of 10 species most often collected with gill nets usually were highest in the RBR tailwater (particularly at Station 1), and catches of the remaining three species were similar among areas or higher at stations outside the tailwater (Figure 7). Species with highest catches at tailwater stations were striped bass, white bass, hybrid bass, sauger, silver redhorse, spotted sucker, carpsuckers, and gizzard shad.

Spatial variation of electrofishing catches was less pronounced (Figure 8). Catches at tailwater stations were similar to those at tributary sites (Stations 4, 5, 6, and 11). Catches in the main-lake samples (Stations 7-10) typically were lowest except for common carp.

Seasonal Trends

The ability to detect seasonal trends was compromised by changes in water level. Both 1986 and 1988 were low-water years, and 1987 was closer to "normal" pool elevations. It is possible that seasonal trends would be affected by changes in water level.

Seasonal trends in gill-net catches tended to be similar in all areas of the lake, with highest catches usually in spring and summer (Figure 9). Electrofishing catches in the tailwater were fairly consistent seasonally, with relatively high catches in May-July and reduced catches in fall and winter (Figure 10). Seasonal patterns were not consistent among years at tributary and main-lake stations. Catches at tributaries were highest in fall 1986, in spring and summer 1987, and in winter 1988.

Is the Tailwater Unique?

Species composition at Stations 1-3 was generally similar to that of other tributary stations within each season, but catches in the tailwater usually exceeded those elsewhere. This suggests that fish abundance is higher in the tailwater than in tributary and main-lake areas.

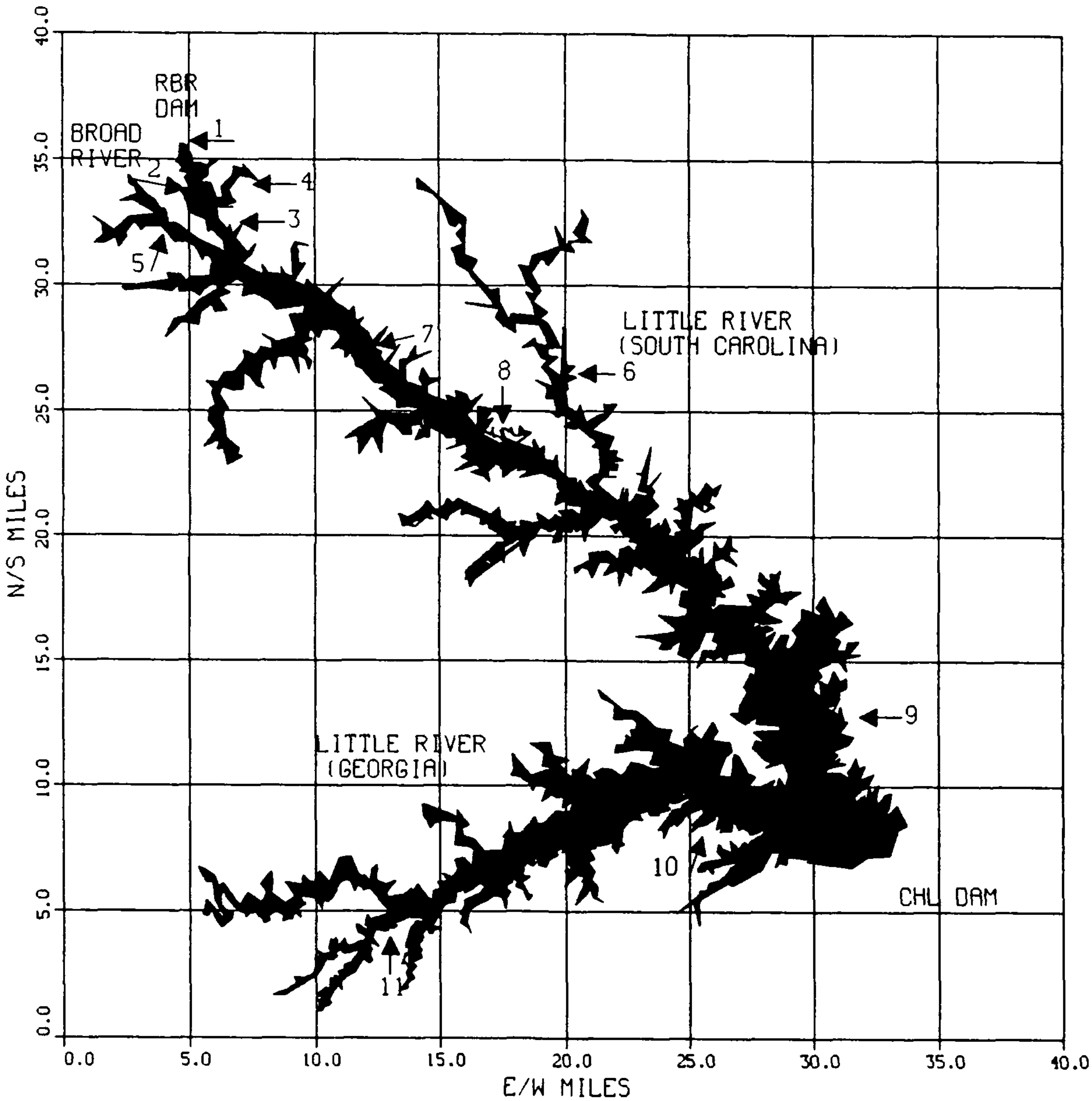
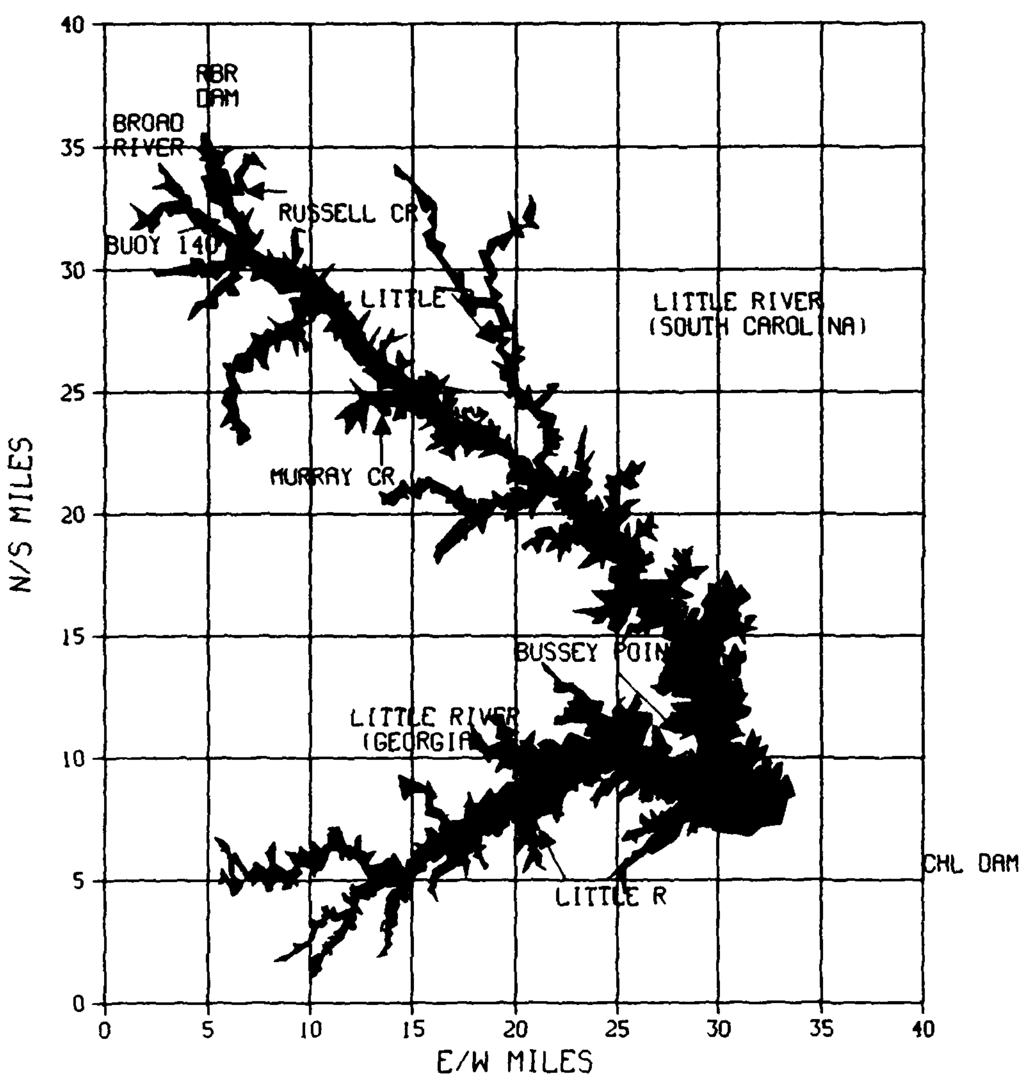


Figure 1. Map of JST Lake, showing gill netting and electrofishing sampling Stations 1-11



STANDING CROP (KG/hA)

COVE	1986	1987
BUOY 140	375	118
BUSSEY POINT	132	401
LITTLE RIVER SC	425	58
MURRAY CREEK	196	203
CLIATT CREEK	NS	112
CHL MEAN	282	178

Figure 2. Cove rotenone sampling locations and between year and among cove variation in total biomass

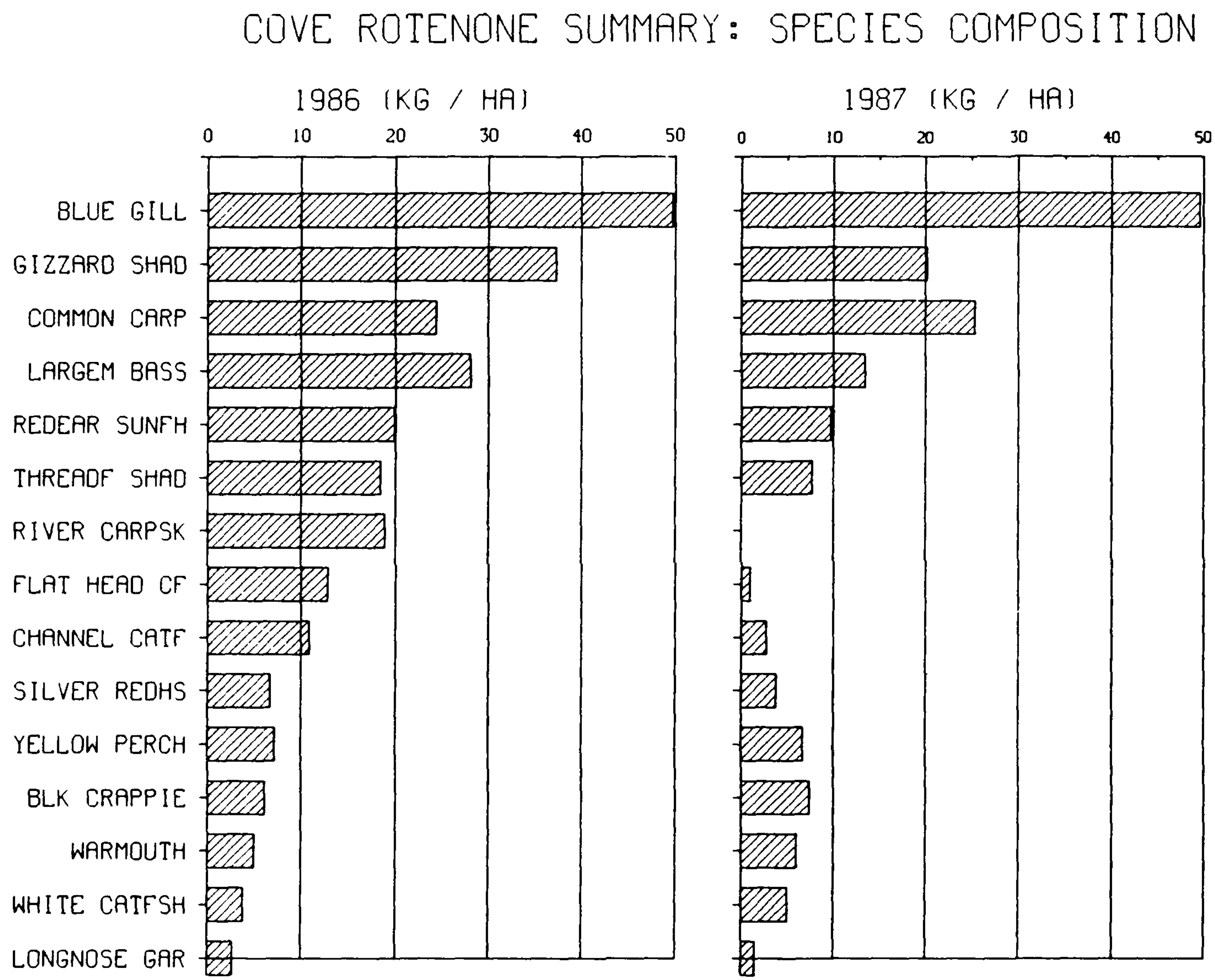


Figure 3. Species composition and biomass estimated by cove rotenone sampling in JST Lake

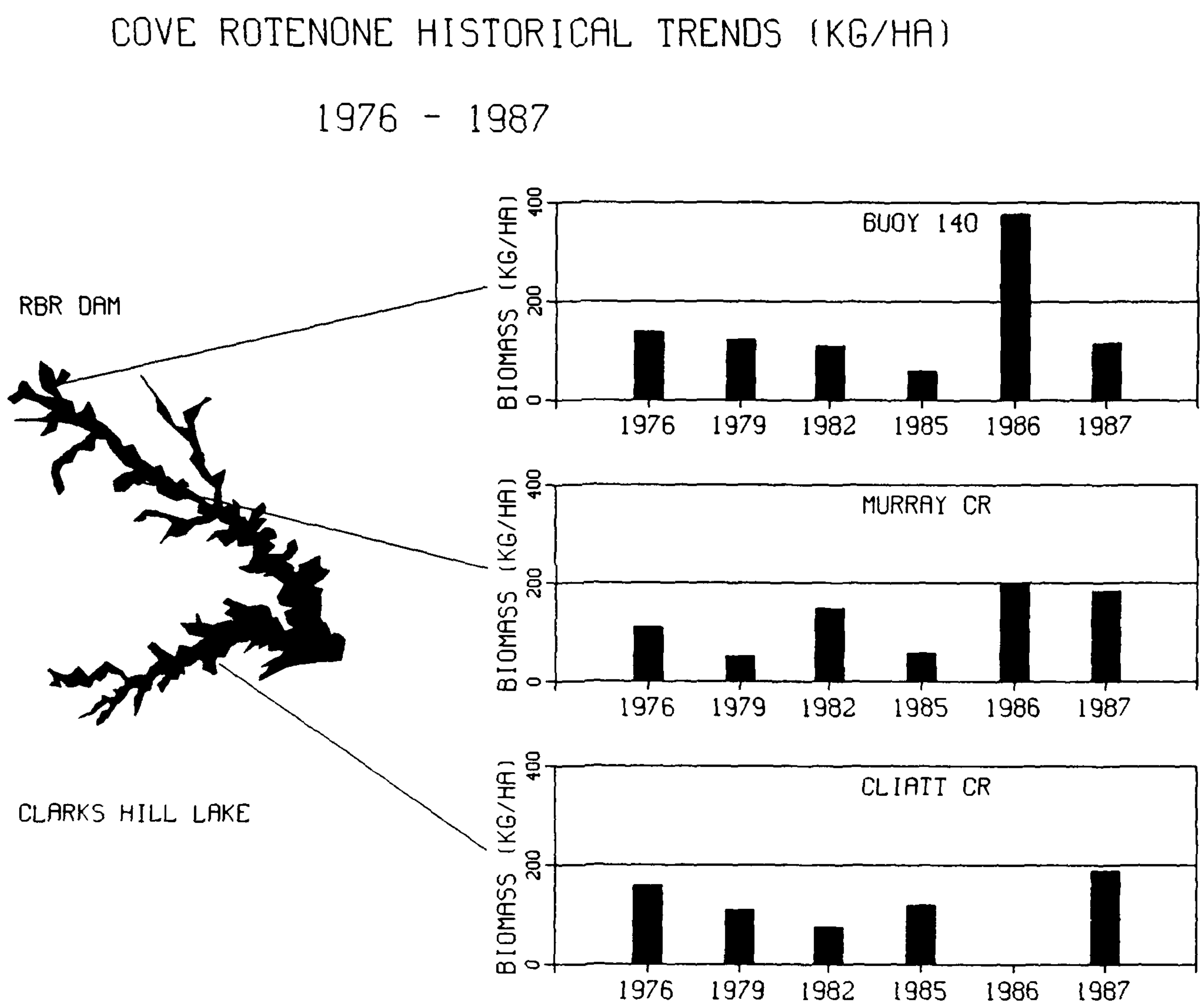


Figure 4. Long-term trends in fish standing crop estimated by rotenone sampling of three coves in JST Lake (Cliatt Creek was not sampled in 1986)

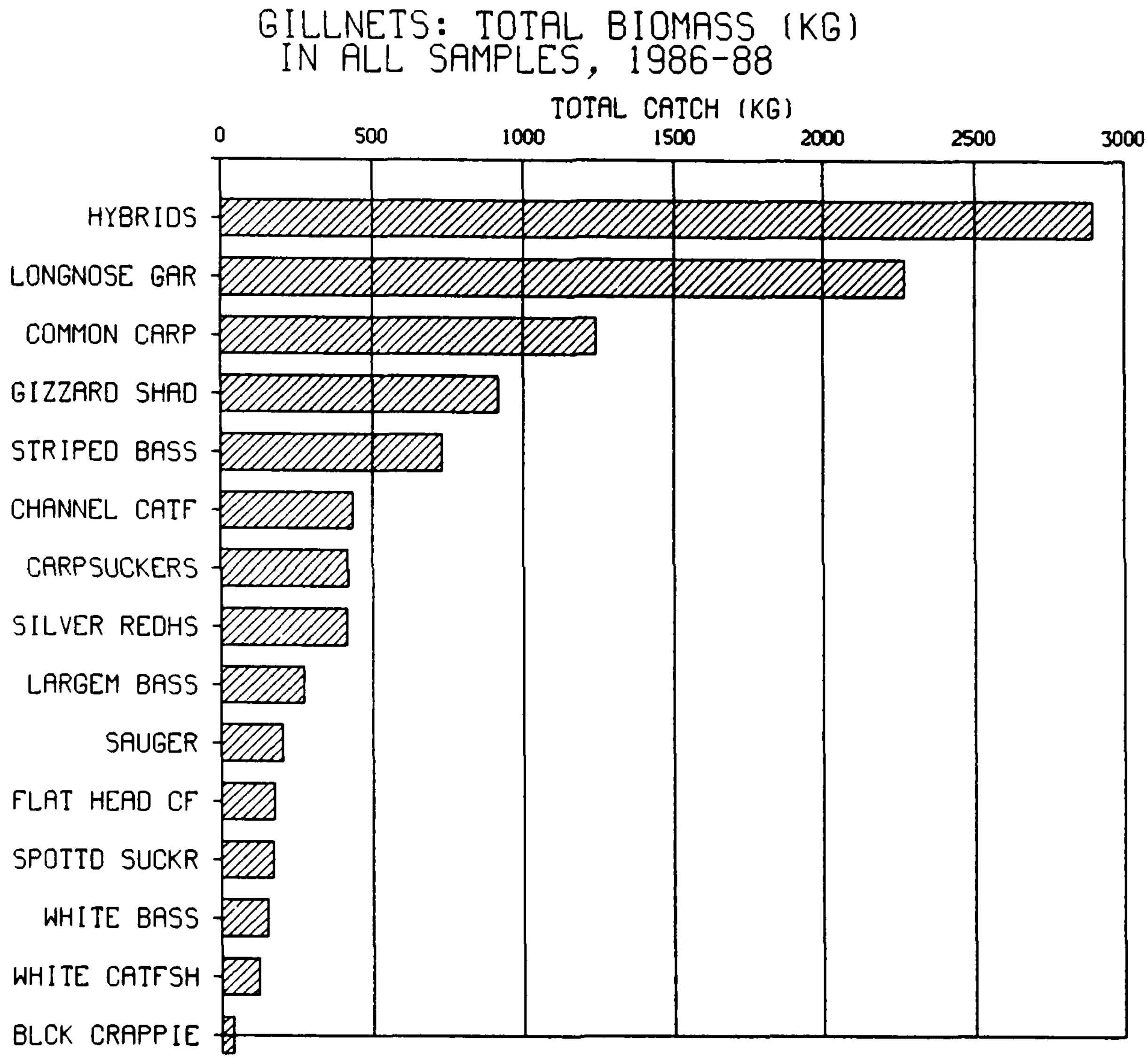


Figure 5. Total biomass of the 15 most common species sampled in gill nets at JST

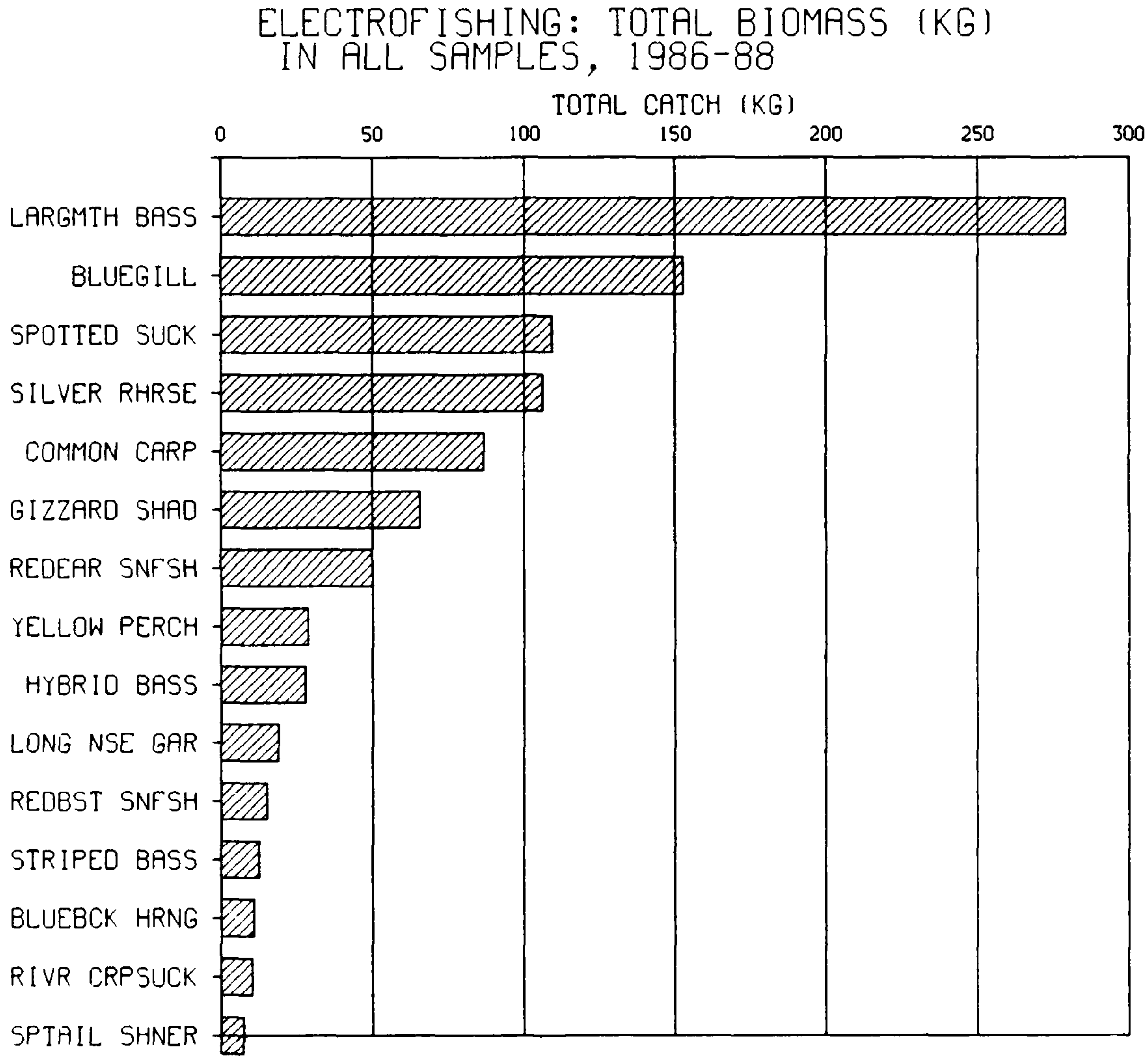


Figure 6. Total biomass of the 15 most common species samples by electrofishing at JST Lake

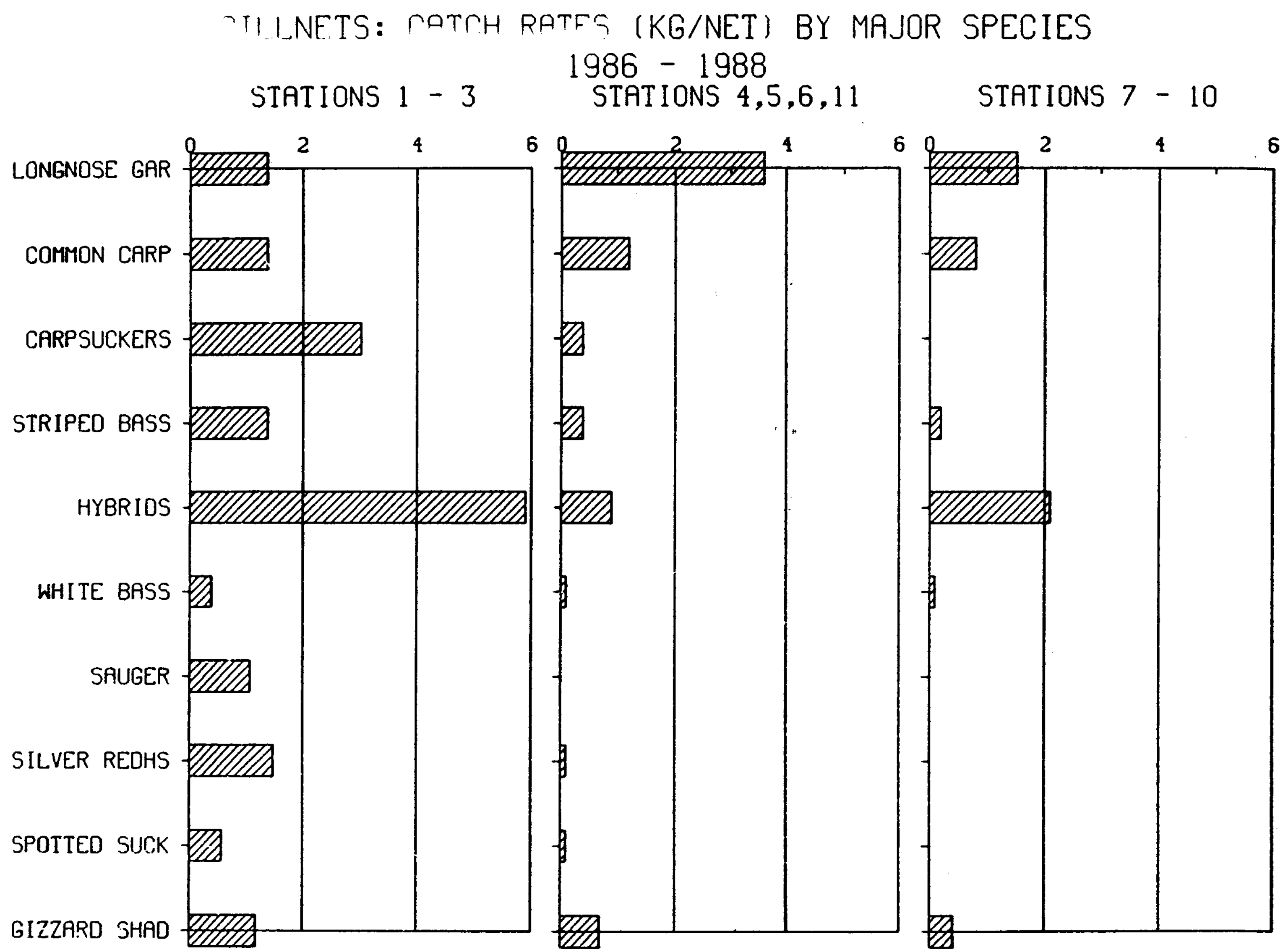


Figure 7. Catches of major species in gill nets set at tailwater (Stations 1-3), tributary (Stations 4, 5, 6, and 11), and main-lake (Stations 7-10) locations in JST Lake

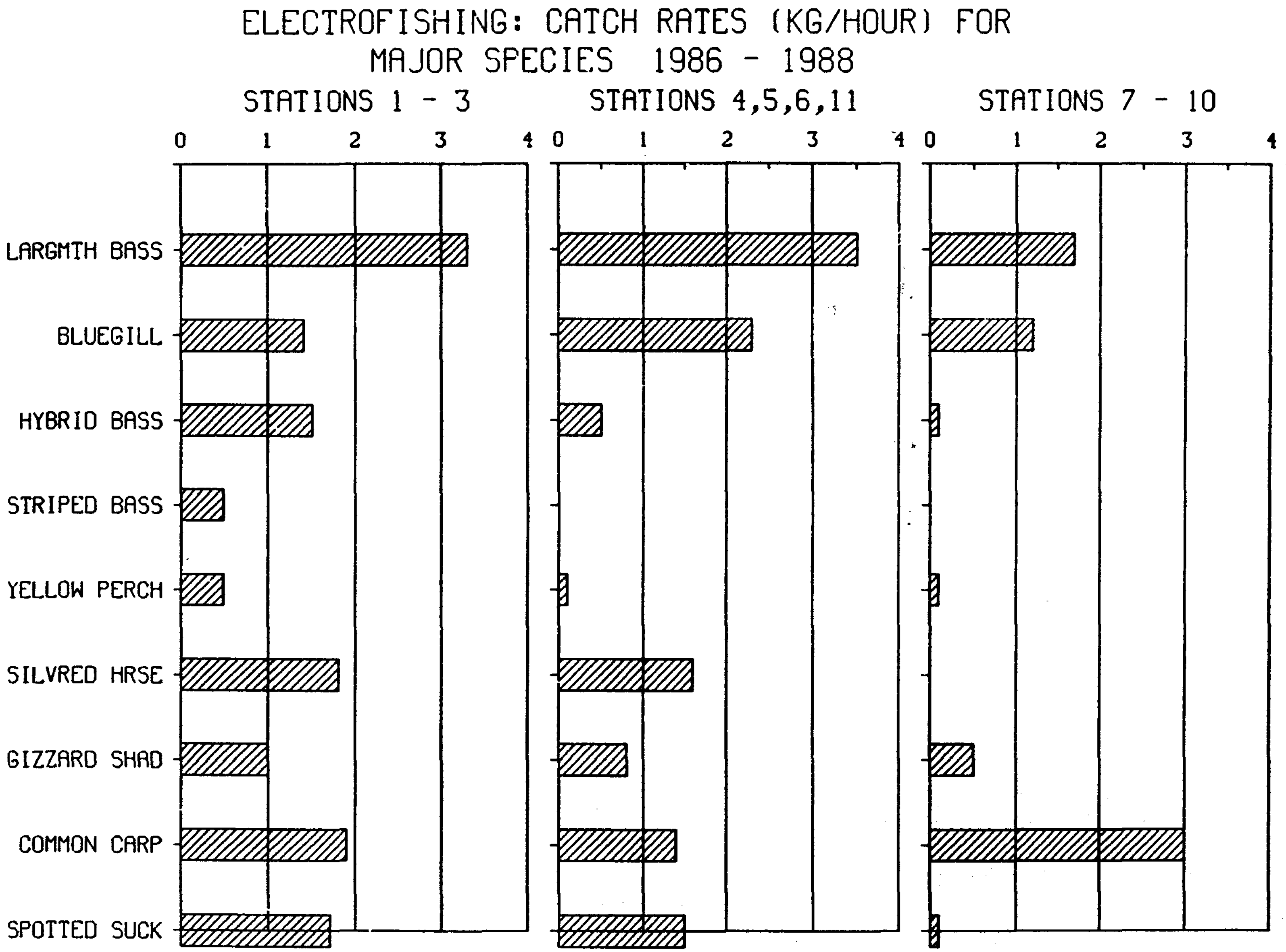


Figure 8. Catches of major species by electrofishing at tailwater (Stations 1-3), tributary (Stations 4, 5, 6, and 11), and main-lake (Stations 7-10) locations in JST Lake

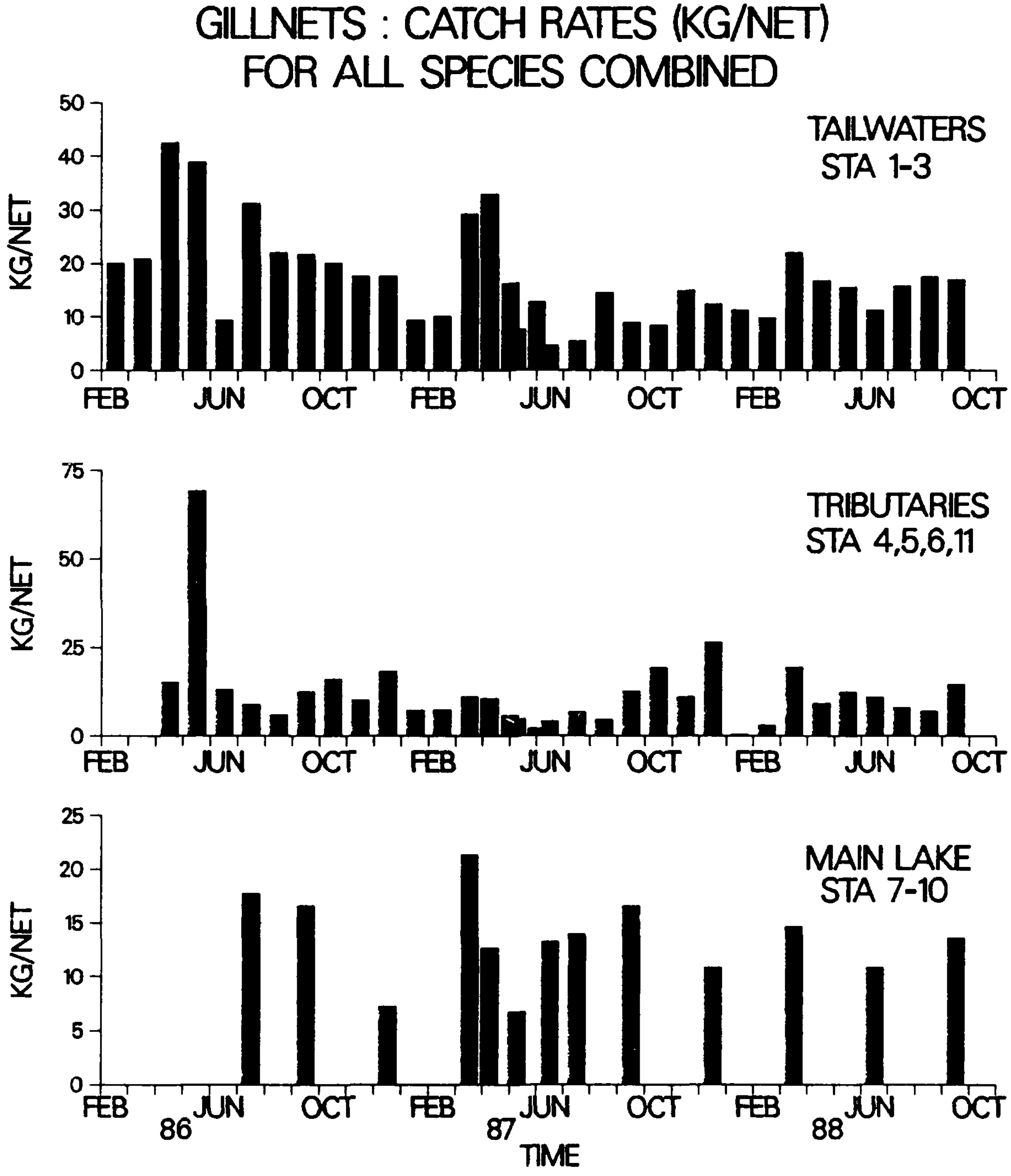


Figure 9. Biomass per gill net by lake location and month for all species sampled with gill nets set in JST Lake

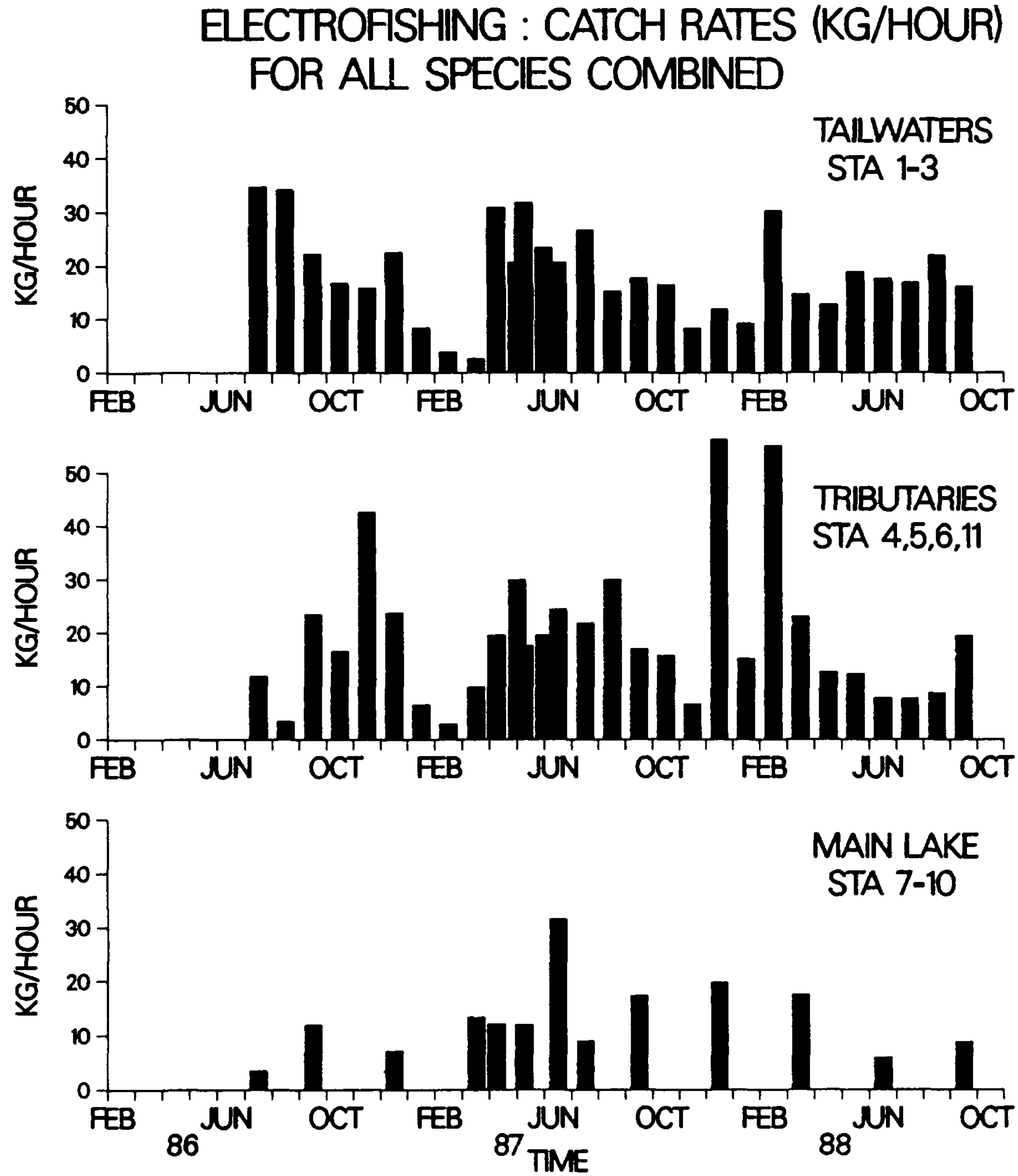


Figure 10. Biomass per hour by lake location and month for all species sampled by electroshocking JST Lake

LAKEWIDE HYDROACOUSTICS AND THURMOND LAKE-RUSSELL TAILWATER COMPARISONS

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Overview

Results of hydroacoustic studies were given in three separate presentations: (a) "Lakewide Hydroacoustics and Thurmond Lake-Russell Tailwater Comparisons" (this presentation), (b) "Near-Field Hydroacoustics" (tailwater and tailrace surveys), and (c) "Comparisons of Richard B. Russell with Other Projects." General methods are given once in this paper, while specific sampling designs are described separately in appropriate presentations.

Introduction

Hydroacoustics involves the use of sonar to obtain information about underwater objects. Sound waves emitted underwater by a transducer strike objects with a density different from water, and a portion of the sound wave that is reflected back is measured and recorded. The position and range (distance from the transducer) of a fish in a sonar beam can be computed from the intensity of its echo and the time lapse between sending sound and receiving the echo. Hydroacoustics usually is used in conjunction with other fish sampling methods such as netting, seining, or electrofishing that provide information on species composition as well as fish size.

Among the many advantages of hydroacoustics over traditional sampling methods is that it is nondestructive and noninvasive of fish and the environment. It can also provide better spatial and temporal coverage than other methods because sampling is rapid and nondestructive. Hydroacoustics can provide quantitative estimates of relative biomass and sizes of fish at multiple depth intervals. The method also permits observations and inferences about fish behavior such as diurnal migrations and distribution.

Sampling with hydroacoustics has several disadvantages. The primary disadvantage is that species cannot be identified without supplemental sampling with other methods. In addition, shallow water cannot be sampled

sampling with other methods. In addition, shallow water cannot be sampled effectively because of electronic distortions close to the transducer and difficulty in separating echoes of fish near the bottom from bottom echoes. The minimum effective depth for hydroacoustic sampling is about 2 m, but it varies some with equipment sensitivity and bathymetric gradients. Fish within submerged timber are often undetectable because of strong obscuring echoes from tree branches. Other interferences may include suspended insect larvae, turbulence resulting from flow, and entrained air caused by wind.

General Hydroacoustic Methods

The hydroacoustic system consisted of a BioSonics model 101 echo sounder with a dual beam 420-kHz transducer transmitting on a 6-deg* beam and receiving on a 6- and 15-deg beam. Echoes were monitored with a Hitachi Oscilloscope and charted with an EPC model 1600 chart recorder. They were digitized with a Sony digitizer and recorded on a Sony video cassette recorder. A BioSonics model 171 tape recorder interface was used to connect the sounder to the digitizer for data transfer and recording.

Acoustic surveys were conducted in a 21-ft Monarch aluminum hull boat that housed the required electronic gear. The transducer was mounted under a 2-ft-long stabilizing fin that was suspended just below the water surface near the bow of the boat. The boat was driven slowly along each transect at as constant a speed as possible so that each part of the transect was sampled with nearly equal effort. Electronic equipment was powered with a portable gasoline generator. Data were recorded on video cassettes during sampling by WES personnel and later sent to Biosonics, Inc., Seattle, WA, for processing. Biosonics used a Biosonics model 121 echo integrator to derive relative biomass data and a Biosonics model 181 dual beam processor for target strength data. Biomass and target strength data sets were placed on 360 K floppy disks and returned to WES, where they were edited, summarized, and analyzed.

The echo integrator accumulated echo intensity readings of individual fish or groups of fish and provided relative biomass estimates per 1-m depth interval and transect segment. Relative biomass estimates were expressed as echo voltage squared per unit volume (or area) of water sampled. Other

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

researchers have correlated these types of data with actual fish biomass per unit of netting effort (see Thorne 1983).

Chart recordings of echoes (echograms) were used to check the validity of relative biomass data from the echo integrator. Plots of integrator data (e.g., Figure 56) were compared visually with echograms, and cells of integrator data were retained when echoes appeared to be from fish. Data cells were excluded if echoes appeared to arise from or include bottom returns, tree stumps or limbs, man-made structures, or other objects such as air bubbles. Fish biomass may have been excluded if it occurred in a cell dominated by a foreign object, or conversely, a foreign object may have been included as biomass if it was in an area dominated by fish echoes. The overall value of edited data sets was very good for surveys near the dam but only fair for the tailwater and lakewide surveys because of the many trees present in those areas.

The dual beam processor identified single fish echoes and computed target strengths (relative size) adjusted for the position of fish in the acoustic beam. This method may cause a biased sampling toward larger fish that are ensonified longer and are more likely to show up as isolated echoes rather than small fish that school. These biases must be considered when evaluating target strength data. Target strength data could not be verified with echograms as were the echo integration data. Spot comparisons with echograms suggested that the dual beam processor was fairly conservative and did not include echoes from objects such as tree limbs or walls that sometimes had to be manually excluded from the integration data.

Frequency distributions of target strengths were summarized instead of length frequencies calculated from target strengths because the regression equation available may not be appropriate for fish in JST. Target strength data (in decibels (dB)) can be converted to fish length using a regression equation that Love (1977) derived from laboratory measurements of several fish species oriented at from 0 to 45 deg from the axis of an acoustical beam (Figure 11). This relation provides an approximation of fish length useful as a frame of reference, but lengths may not be highly accurate.

Lakewide Methods

Hydroacoustic surveys were used to assess and compare the biomass, numbers, and sizes of fish among four seasons, three years (1986-88), and three areas (JST tributaries, JST Lake, and RBR tailwater). Lakewide surveys of tributaries and main-lake stations were conducted in July, September, and December 1986; in March through July, September, and December 1987, and in March, June, and September of 1988. All lakewide surveys were conducted during daylight because of logistical and safety considerations. Tributary stations (5, 6, and 11) were composed of 4 transects each in July and September 1986 and 11 transects each through September 1988. Every main-lake station (7, 8, 9, and 10) had four transects. Adjacent transects at lakewide stations were sampled in alternate directions, but no attempt was made to run these transects in the same direction each time. Surveys were conducted within 1 week of gill netting and electroshocking so that the latter methods could provide somewhat concurrent species information.

Results

Lakewide

Average relative biomass, by station and month sampled over 3 years (Figure 12), often appeared to be higher in tributaries than in main-lake stations. However, most apparent differences were insignificant because of high sample variability among transects. Highest biomass estimates occurred in December 1986 and 1987 at several stations. The 1986 peaks were thought to be sampling artifacts caused by interference from suspended debris, which appeared during a period of high runoff following extended drought. Debris-laden water may have entered the lake at tributary stations during December and contributed to high biomass estimates. Many of the acoustic targets did not appear to be fish based upon visual inspection of echograms, but this observation could not be confirmed by other methods. However, gill-net data from many of these stations showed a number of large gar that could have produced the echograms observed.

Figure 13 shows the same data, but with the stations averaged by main-lake or tributary category and month sampled. Relative biomass at tributary stations was somewhat higher than at main-lake stations in some months such as July 1986 and December 1987, but analysis of variance and Duncan's multiple

range testing indicated that most other differences were not significant. No consistent seasonal trends were apparent from available data. However, sampling was limited in 1986 and 1988.

Lake-tailwater comparisons

Daytime tailwater data (Stations 2 and 3) were averaged by sample date and plotted with tributary and main-lake data (Figure 14). In 1986 and 1987, two tailwater surveys were conducted in April and in May; tailwaters were surveyed only once in other months. Biomass in the tailwater tended to peak in late summer and fall, whereas lakewide sampling revealed no apparent seasonal trend. Average monthly biomass in the tailwater did not differ significantly from that measured during similar months in lakewide surveys, except in September 1986 and 1987, when it was higher in the tailwater than in the main lake. Average relative biomass was higher in tributaries to JST Lake than in the RBR tailwater in July and December 1986 and in December 1987.

Frequency distributions of target strengths were created to compare the relative size of fish in tributary, main lake, and tailwater areas over 3 years (Figures 15-19). A sample size of at least 50 individuals was required before a histogram was plotted. Generally, target strength distributions were quite variable, although more small than large fish were nearly always present, as would be expected biologically. Although frequency distributions of target strengths were variable among locations from month to month, average seasonal and annual target strengths did not differ significantly among locations. Seasonally, target strength distributions included more large targets in winter and spring and then shifted to include more small targets in summer possibly reflecting young of year fish recruitment (Figures 16-19).

Summary

Biomass levels were usually higher at tributary than at main-lake stations, although this result was not statistically significant in most cases. Biomass in the tailwater usually was similar to that in the lakewide surveys. Peak biomass occurred in late summer in the tailwater, and for 2 of 3 years, the peak was higher in the tailwater in September than it was in the

lakewide stations. Mean target strengths were similar in tributary, main-lake, and tailwater areas on an annual and seasonal basis.

Literature Cited

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Thorne, R. E. 1983. "Hydroacoustics," pp 239-259 in L. A. Nielson and D. L. Johnson, eds., Fisheries Techniques, American Fisheries Society, Bethesda, MD.

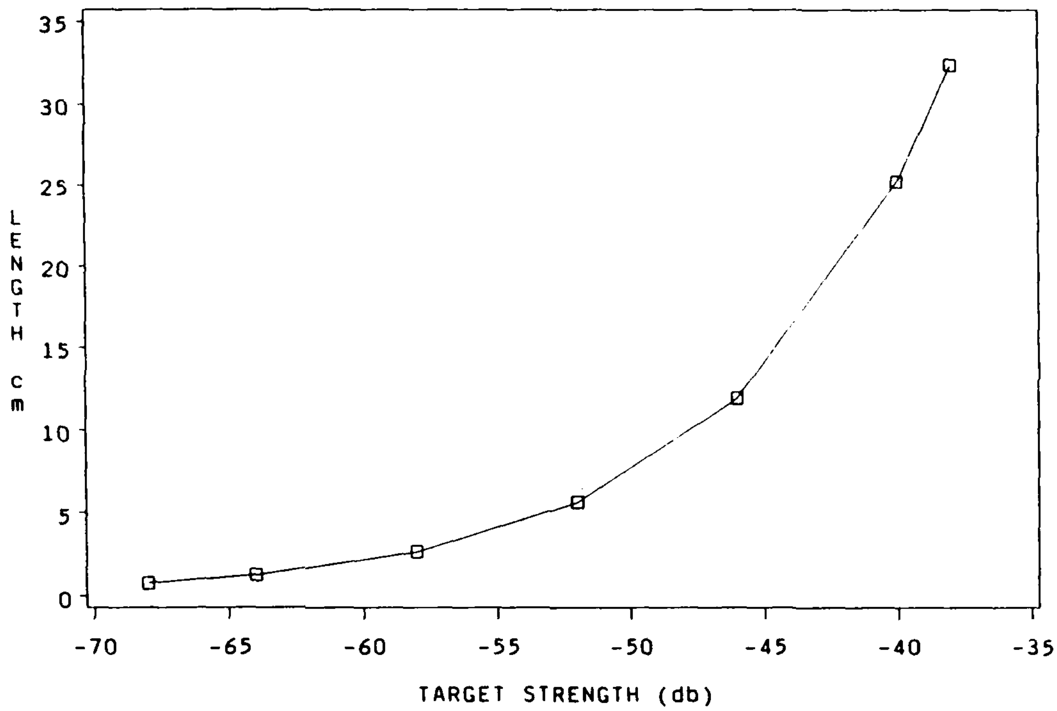

Figure 11. Relation of target strength (dB) to fish length from measurements of fish oriented at from 0- to 45-deg angles to the acoustic beam, with equal probability of being at every angle (Love 1977)

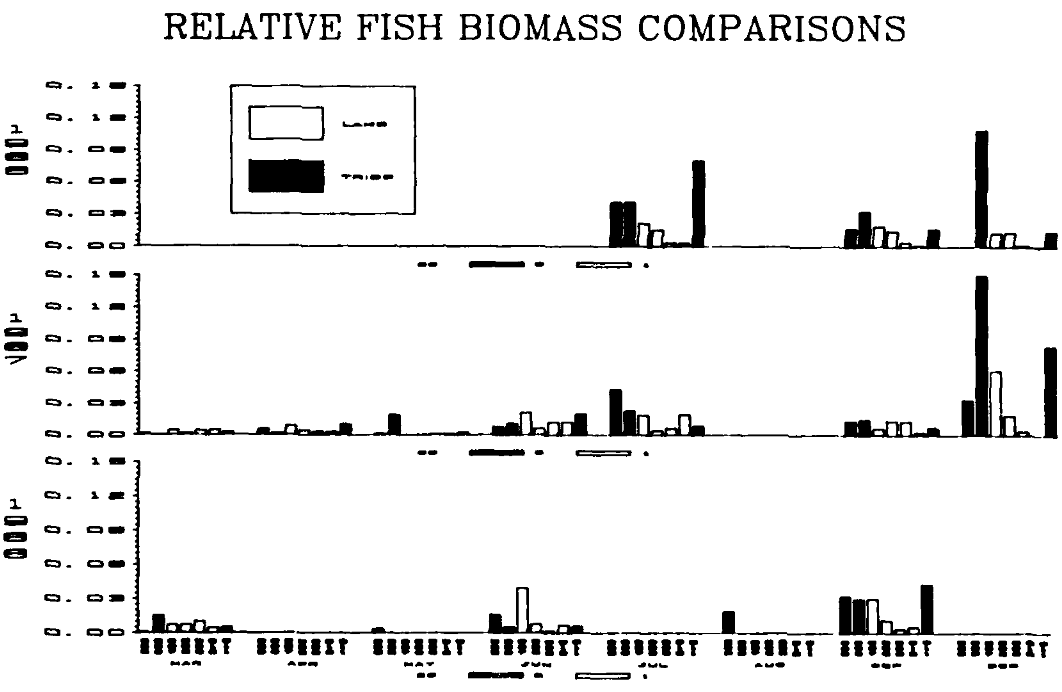

Figure 12. Relative fish biomass measured acoustically in JST Lake at various stations, 1986-1988. Tributary stations (5, 6, and 11) are indicated by black bars while main-lake stations (7-10) are indicated by white bars. Only Station 5 was sampled in May and August 1988, and Station 10 was not sampled in December 1987

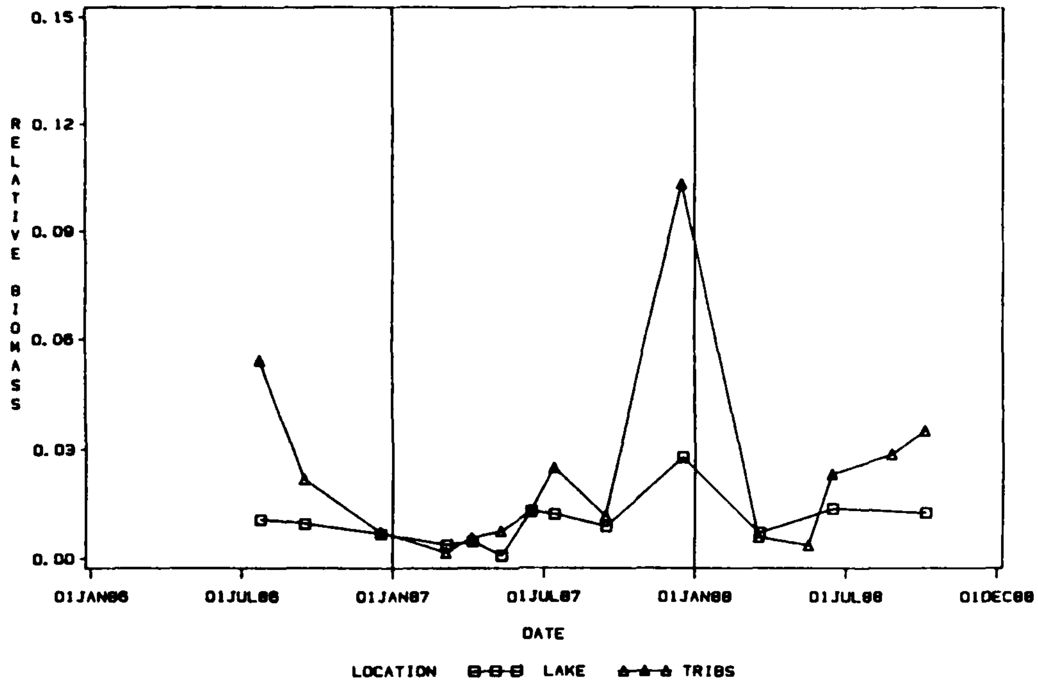

Figure 13. Relative fish biomass measured acoustically in JST (formerly Clarks Hill Lake) Lake, 1986-1988, with data pooled by tributary or main-lake location. Tributary values for May and August 1988 were based on Station 5 only

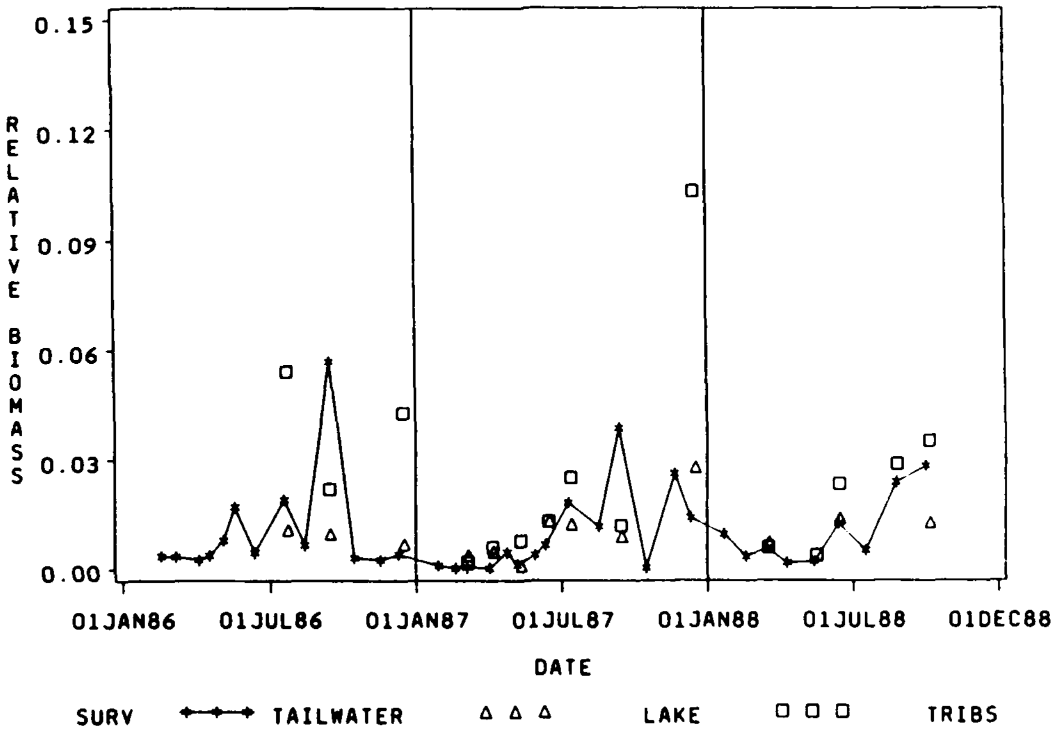

Figure 14. Relative biomass measured acoustically in JST Lake and tributaries and compared with estimates from RBR tailwater stations, 1986-1988. Tributary values for May and August 1988 are based on Station 5 only. Tailwater transects were not weighted by length when averaged

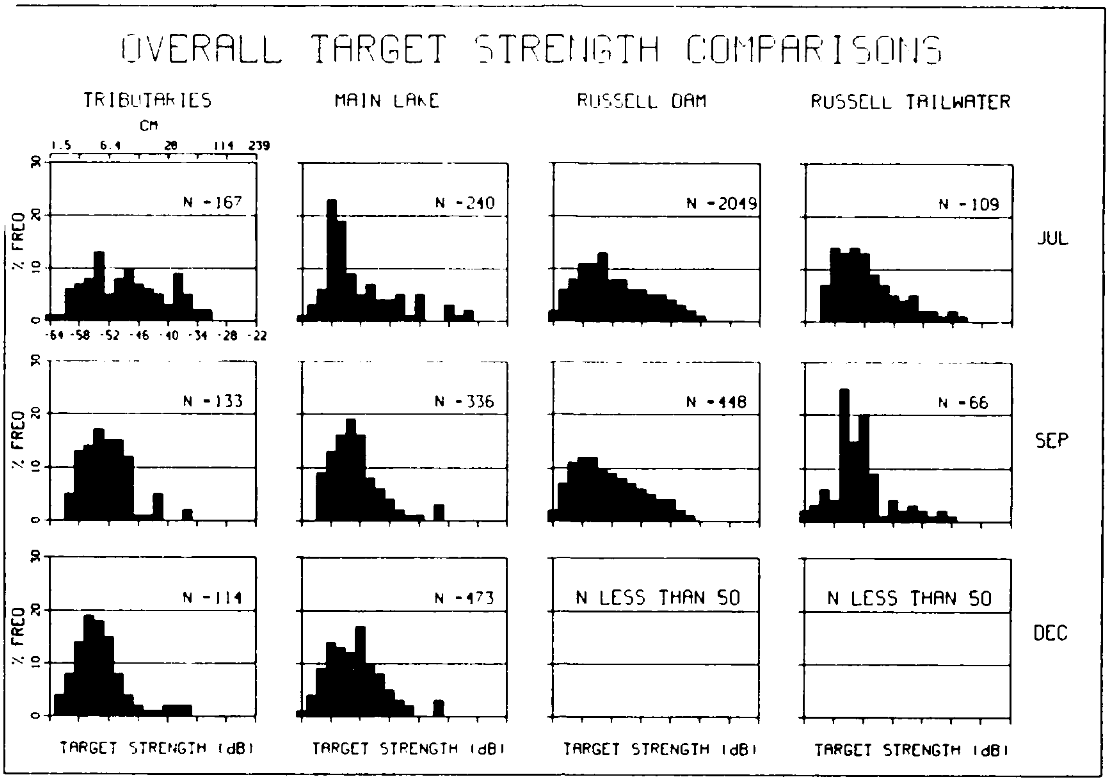

Figure 15. Comparison of acoustic size distributions of fish at various locations in JST Lake in July, September, and December 1986

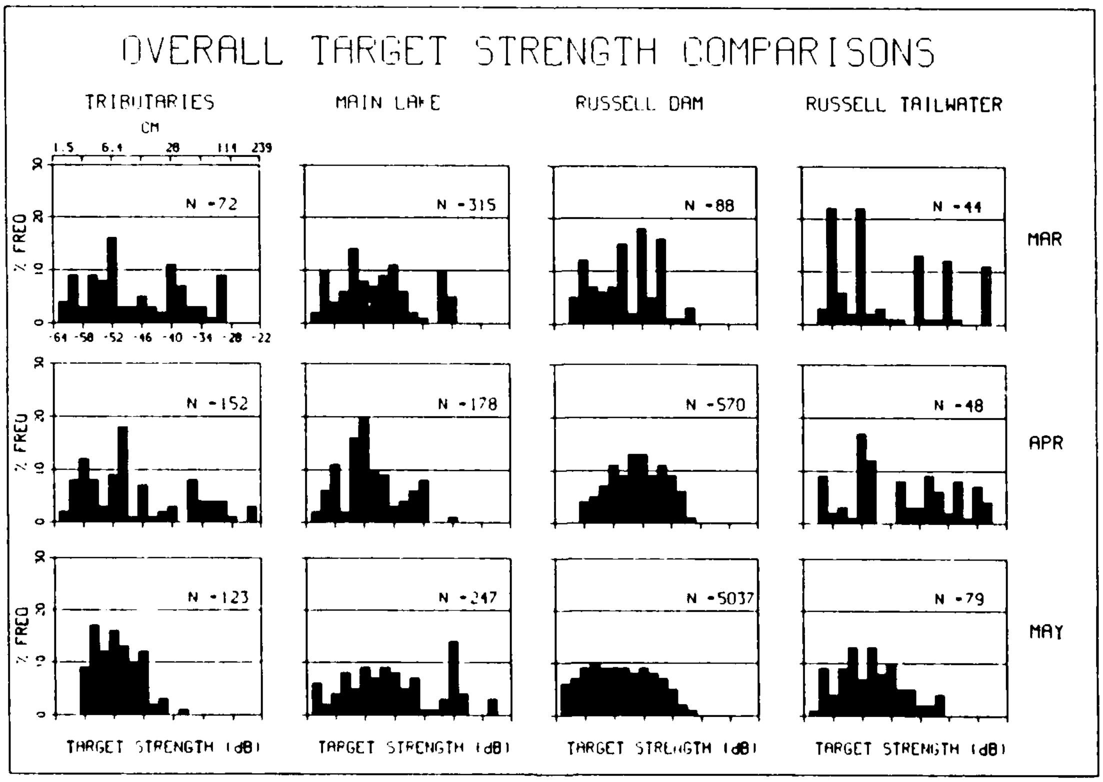

Figure 16. Comparison of acoustic size distributions of fish at various locations in JST Lake in March, April, and May 1987

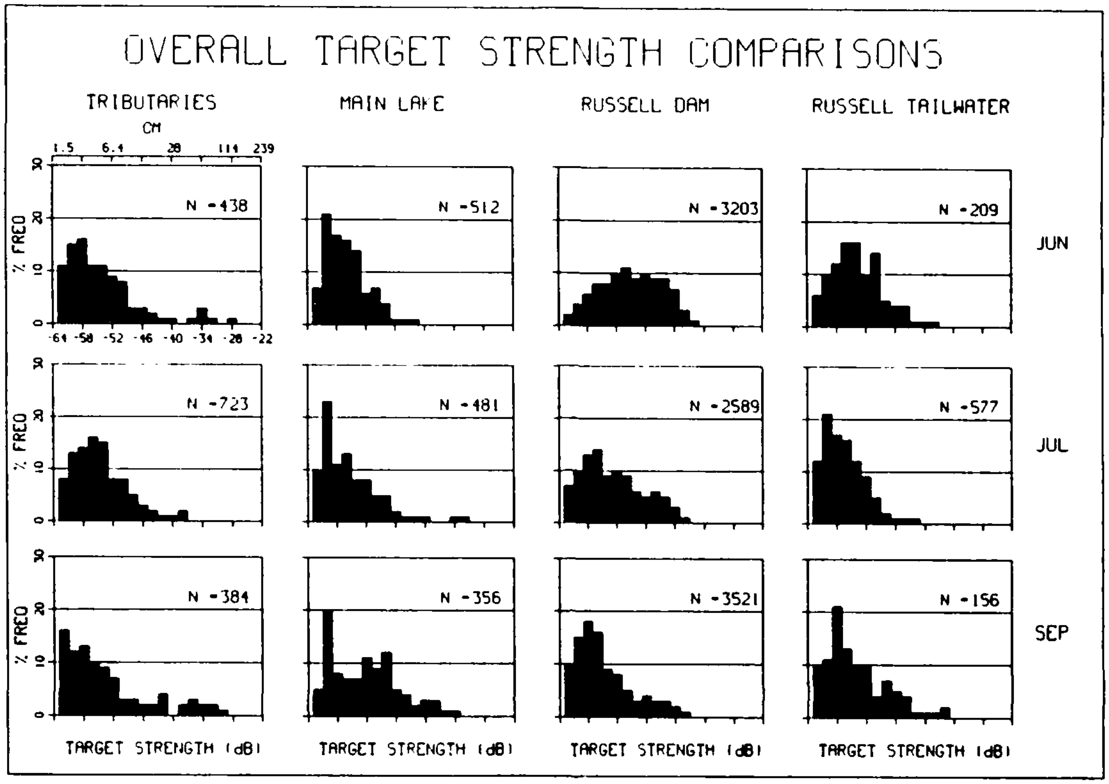

Figure 17. Comparison of acoustic size distributions of fish at various locations in JST Lake in June, July, and September 1987

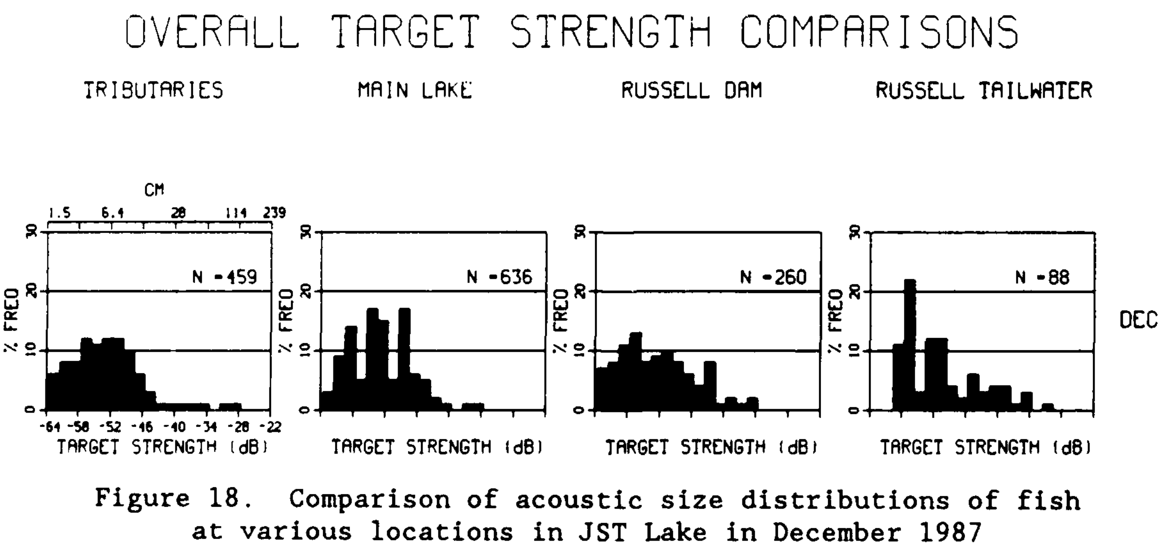

Figure 18. Comparison of acoustic size distributions of fish at various locations in JST Lake in December 1987

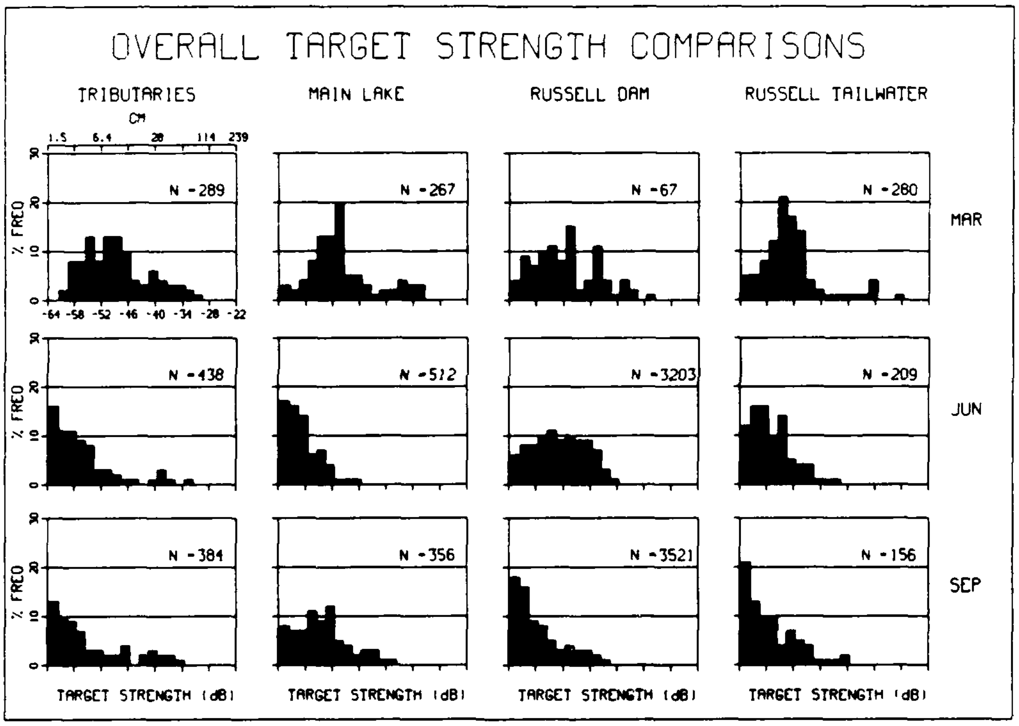

Figure 19. Comparison of acoustic size distributions of fish at various locations in JST Lake in March, June, and September 1988

SPATIAL AND TEMPORAL PATTERNS OF ICHTHYOPLANKTON ABUNDANCE

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Introduction

Ichthyoplankton surveys can be used to define the timing and magnitude of reproduction for various species of fish, particularly those having pelagic early life stages. Limited mobility of larvae can make them vulnerable to entrainment, and knowledge of spatial and temporal patterns can help define the potential for entrainment and identify operational guidelines for minimizing entrainment. The purpose of this paper is to summarize the lakewide results of ichthyoplankton sampling done in 1987 and 1988. Specific questions to be addressed are:

a. What are the spatial and temporal patterns of fish reproduction in JST Lake?

b. Is the tailwater area unique?

Methods

Ichthyoplankton samples were collected at 12 stations in 1987; these included one site in the RBR forebay area (Station 0) and 11 stations in JST Lake that corresponded to the stations used for routine electrofishing and gill netting. Samples were collected at 2-week intervals at night from February through June. Samples were collected at midchannel using stepwise oblique tows of 0.5-m-diam conical plankton net with 0.505-mm mesh. Each tow began at a depth of 4 m and ended at the surface. Four replicate tows were collected. Larvae were identified according to developmental stage, and results were expressed as number per 100 m^3. These sampling techniques are most effective for species whose larvae move (or are transported) offshore to the midchannel sampling sites.

Methods in 1988 were identical to 1987 except for the following. Station 0 was deleted because few larvae were collected there in 1987. Stations 5-11 were sampled at 4-week intervals instead of every 2 weeks.

Results

Conclusions regarding temporal and spatial patterns of ichthyoplankton are based primarily on comparisons of species composition, temporal patterns of appearance of taxa, and differences in relative abundance among areas. About 45,000 larvae were collected in the 2 years studied (Table 1). The four

Table 1

Total Number of Fish Larvae Collected at All Sampling Stations in JST Lake, 1987-88

Species	1987	1988
Clupeids	22,932	16,469
Crappies	2,231	624
Sunfish	1,212	600
Yellow perch	664	288
White bass	64	57
Common carp	31	23
Darters	39	10
Shiners	9	7
Black basses	1	1

major taxa in both years included clupeids (threadfin shad, gizzard shad, and blueback herring), crappies (white crappie and black crappie), sunfish (bluegill, redbreast, redear, and several others), and yellow perch. These four groups made up >98 percent of the larvae collected at all sites in both years. Further assessments of spatial and temporal variation were restricted to these groups.

Species composition of the samples was similar among regions of the lake in both years (Table 2). For purposes of comparison, regions of the lake were

Table 2

Percent Composition of Major Ichthyoplankton at Tailwater (TW), Tributary (TRIB), and Main-Lake (ML) Stations of JST Lake, 1987-88

	1987			1988		
Taxon	TW	TRIB	ML	TW	TRIB	ML
Clupeids	84	82	89	92	89	90
Crappies	8	10	5	5	5	4
Sunfish	5	5	4	2	5	3
Yellow perch	2	3	2	2	1	2

defined as tailwater (Stations 1-3), tributary (Stations 4, 5, 6, and 11), or main lake (Stations 7-10).

Temporal trends

Spawning chronology of the four major taxa (regions combined) was similar in both years (Figures 20 and 21). Yellow perch were the earliest spawners, followed by crappies, clupeids, and sunfish. Spawning peaks were about 1 month later in 1988 than 1987. The timing of spawning was similar among regions of the reservoir within each year. For example, peak densities of larval clupeids occurred during mid-June at tailwater, tributary, and main-lake stations in 1987 (Figure 22). Similar patterns occurred in both years for sunfish, crappies, and yellow perch (Figures 23-25).

Spatial patterns

Average densities of larval fish (number per 100 m^3) for all samples in each region pooled within each year showed consistently higher abundance at tributary stations than at others (Figure 26). In general, densities were lowest at the tailwater stations. This also was the predominant pattern for less-abundant species (Table 3).

Table 3

Total Number of Larvae Collected for the Relatively Rare Taxa at Tailwater (TW), Tributary (TRIB), and Main-Lake (ML) Stations of JST Lake, 1987-88

	1987			1988		
Taxon	TW	TRIB	ML	TW	TRIB	ML
Morone spp.	6	41	17	2	49	4
Common carp	9	6	16	5	0	0
Darters	0	6	33	2	1	8
Shiners	3	1	5	0	4	2
Black basses	0	1	0	0	1	0

Conclusions

Species composition and temporal trends in abundance of fish larvae were similar among all parts of the reservoir in 1987 and 1988. Larvae were present in the tailwater area from March through July of both years.

Abundance of larvae at the tailwater stations was lower than abundance at tributary or main-lake stations. This distribution may indicate a low

amount of reproduction in the tailwater area, or that releases from RBR Dam reduced densities in the tailwater area. The latter possibility is discussed in greater detail in the tailwater ichthyoplankton presentation (Zimpfer, this volume).

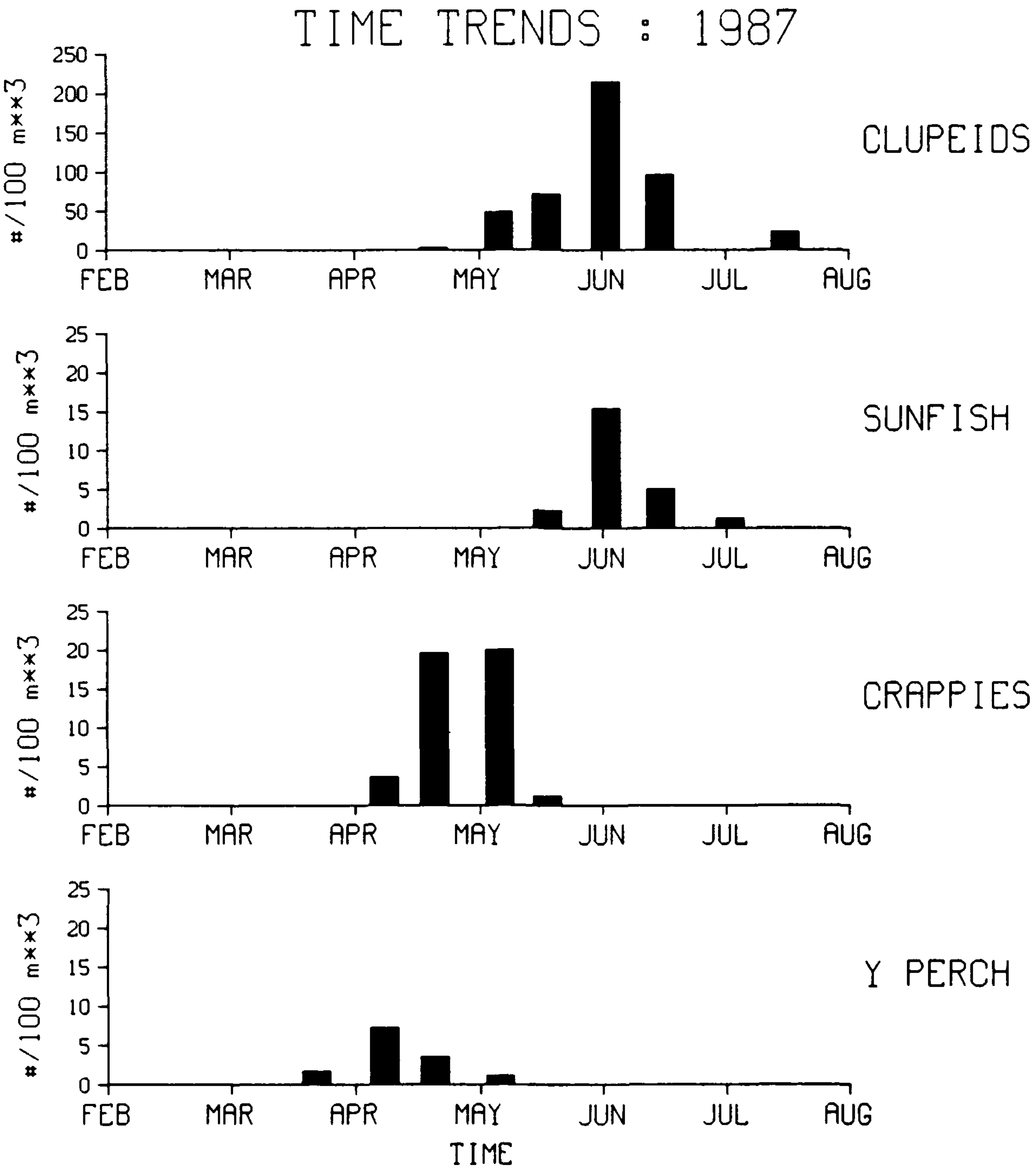

Figure 20. Temporal trends in abundance of larval fishes in JST Lake, all stations combined, 1987

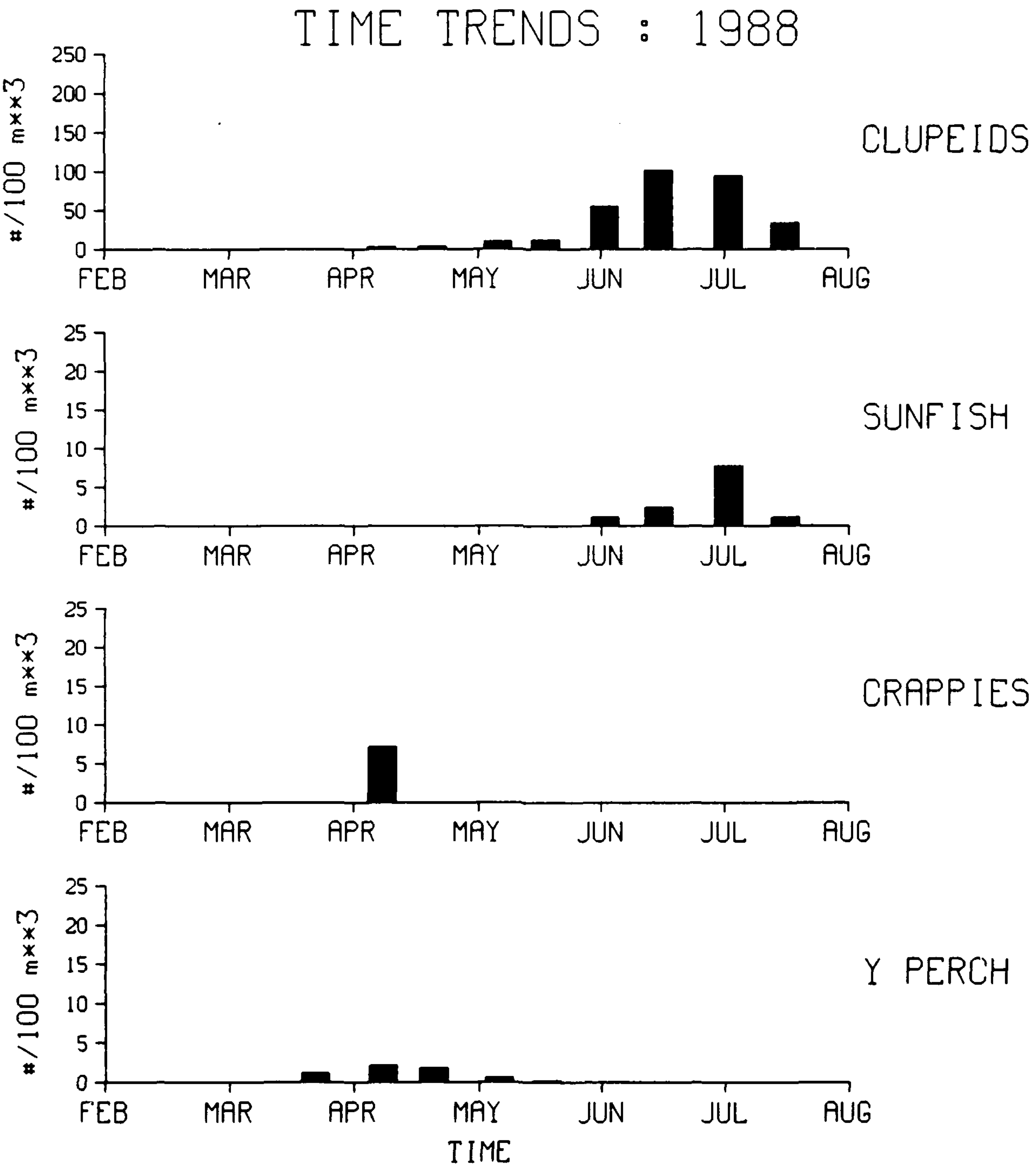

Figure 21. Temporal trends in abundance of larval fishes in JST Lake, all stations combined, 1988

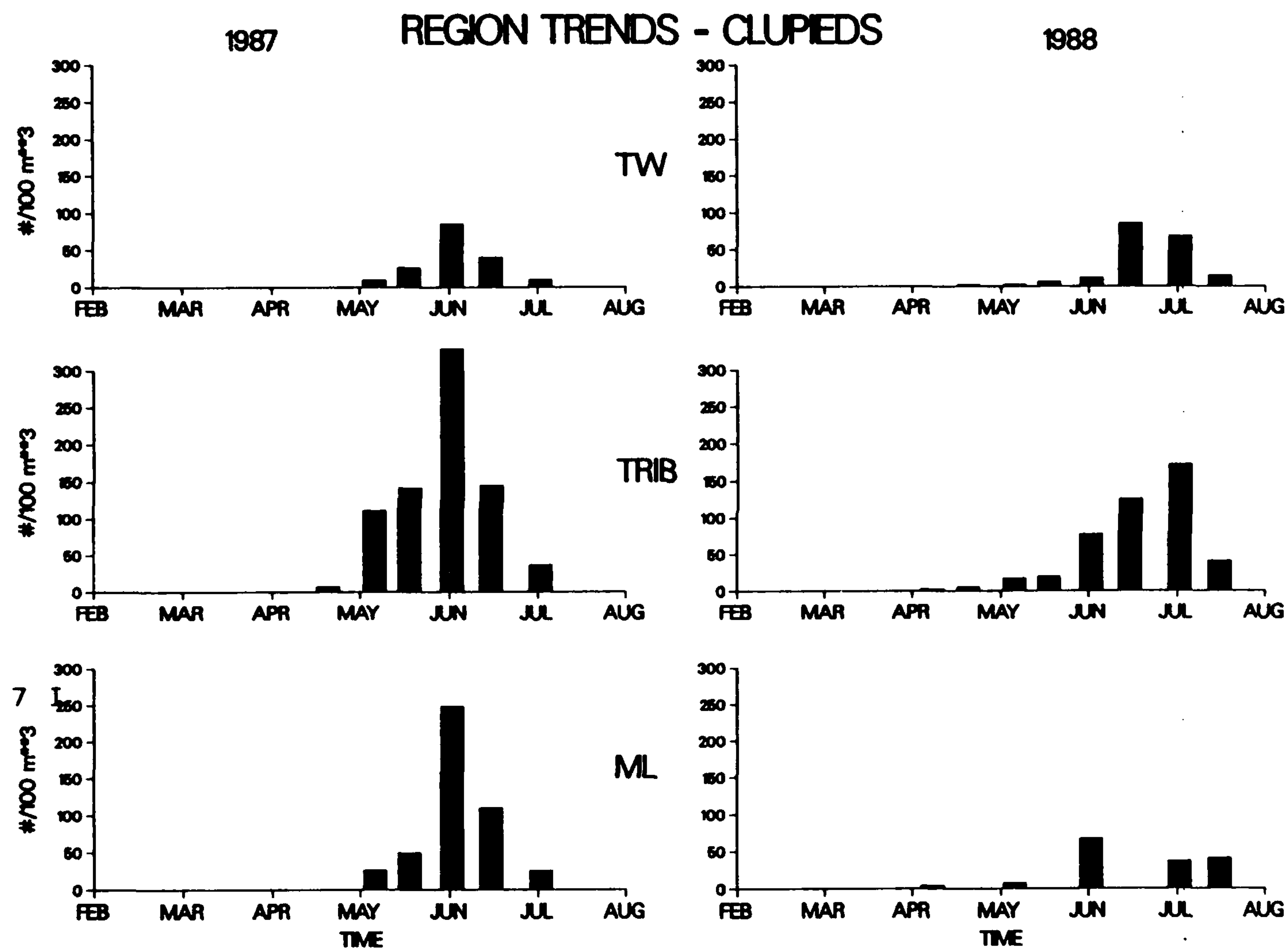

Figure 22. Temporal trends in abundance of larval clupeids at tailwater (TW), tributary (TRIB), and main-lake (ML) stations at JST Lake, 1987-88

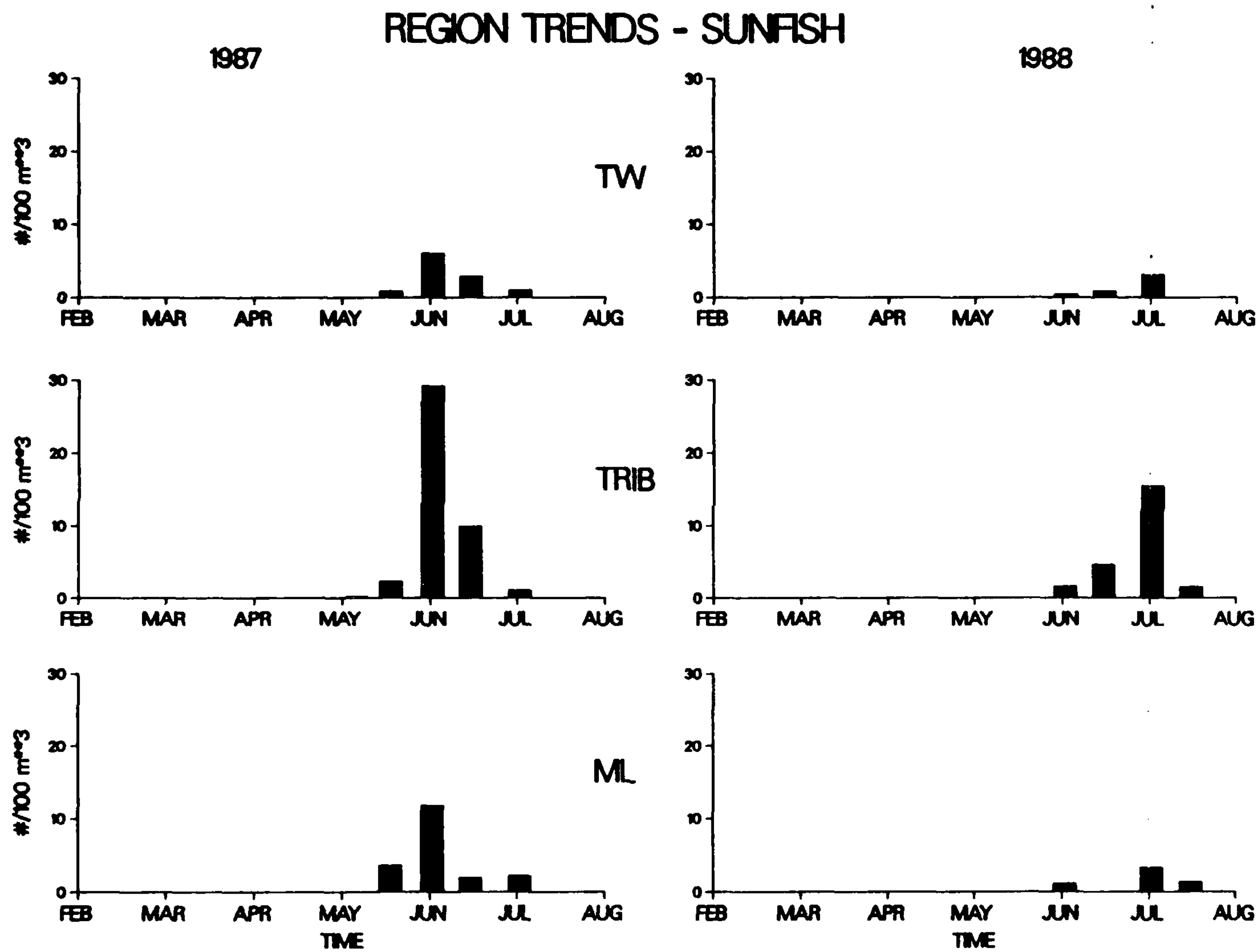

Figure 23. Temporal trends in abundance of larval sunfish at tailwater (TW), tributary (TRIB), and main-lake (ML) stations at JST Lake, 1987-88

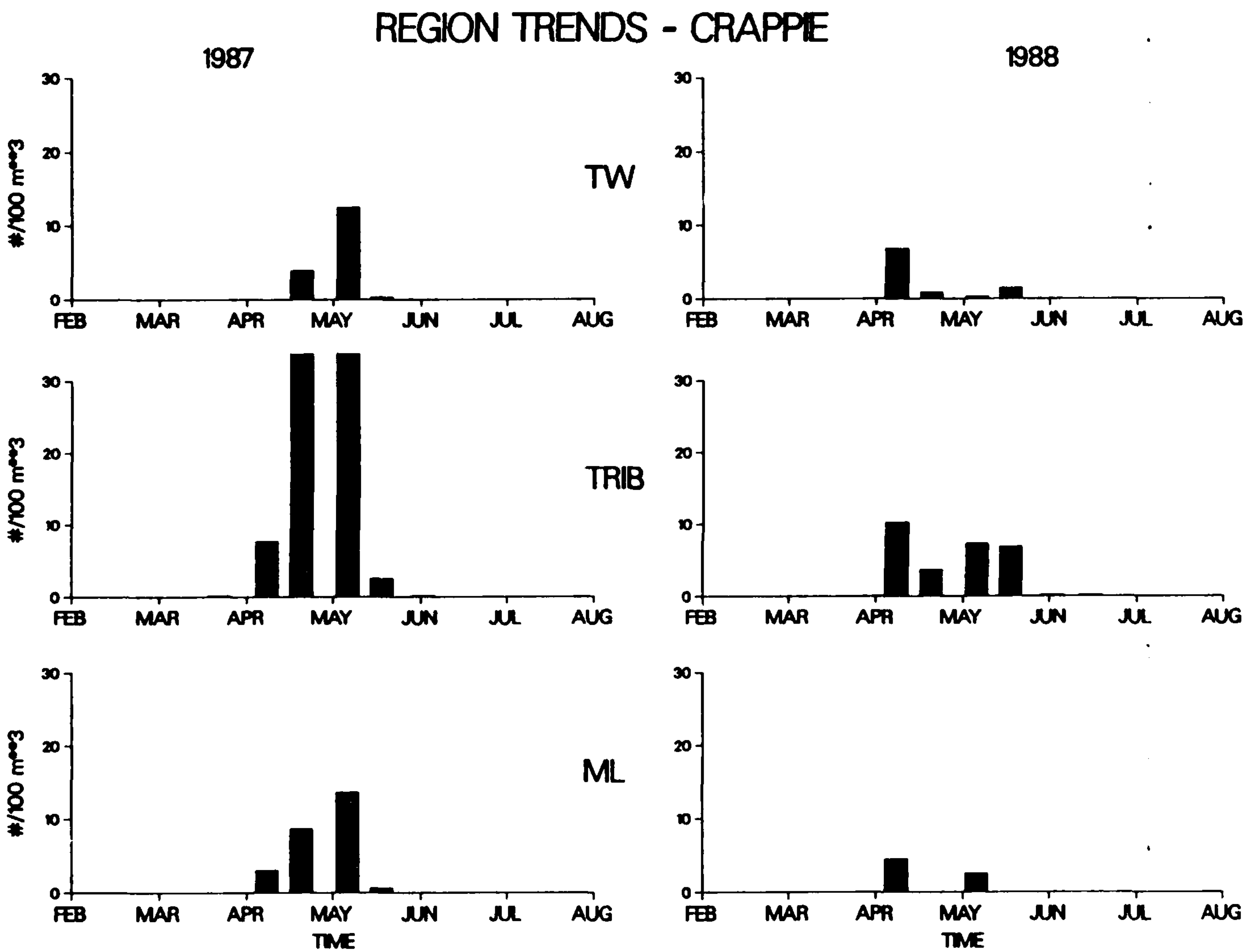

Figure 24. Temporal trends in abundance of larval crappies at tailwater (TW), tributary (TRIB), and main-lake (ML) stations at JST Lake, 1987-88

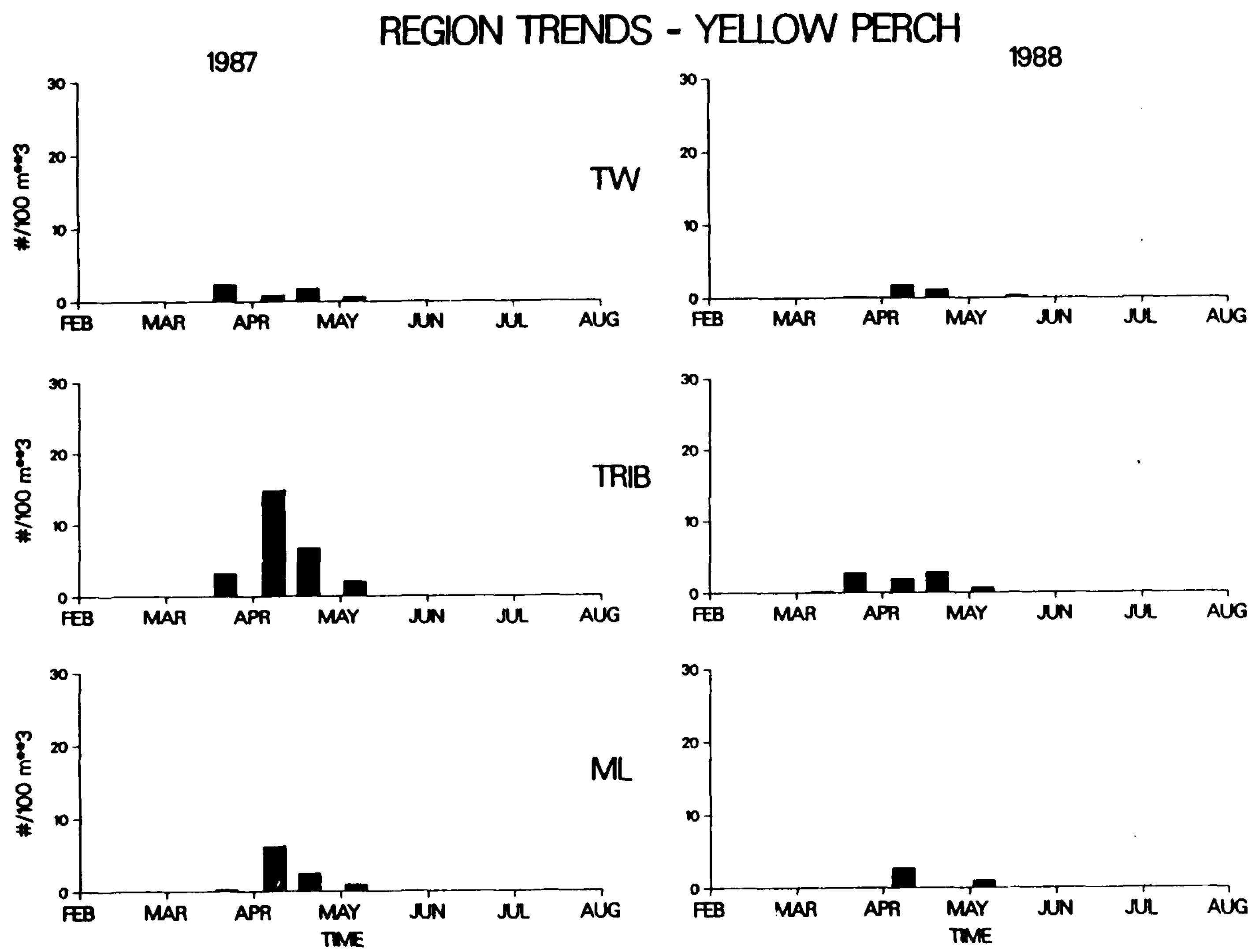

Figure 25. Temporal trends in abundance of larval yellow perch at tailwater (TW), tributary (TRIB), and main-lake (ML) stations at JST Lake, 1987-88

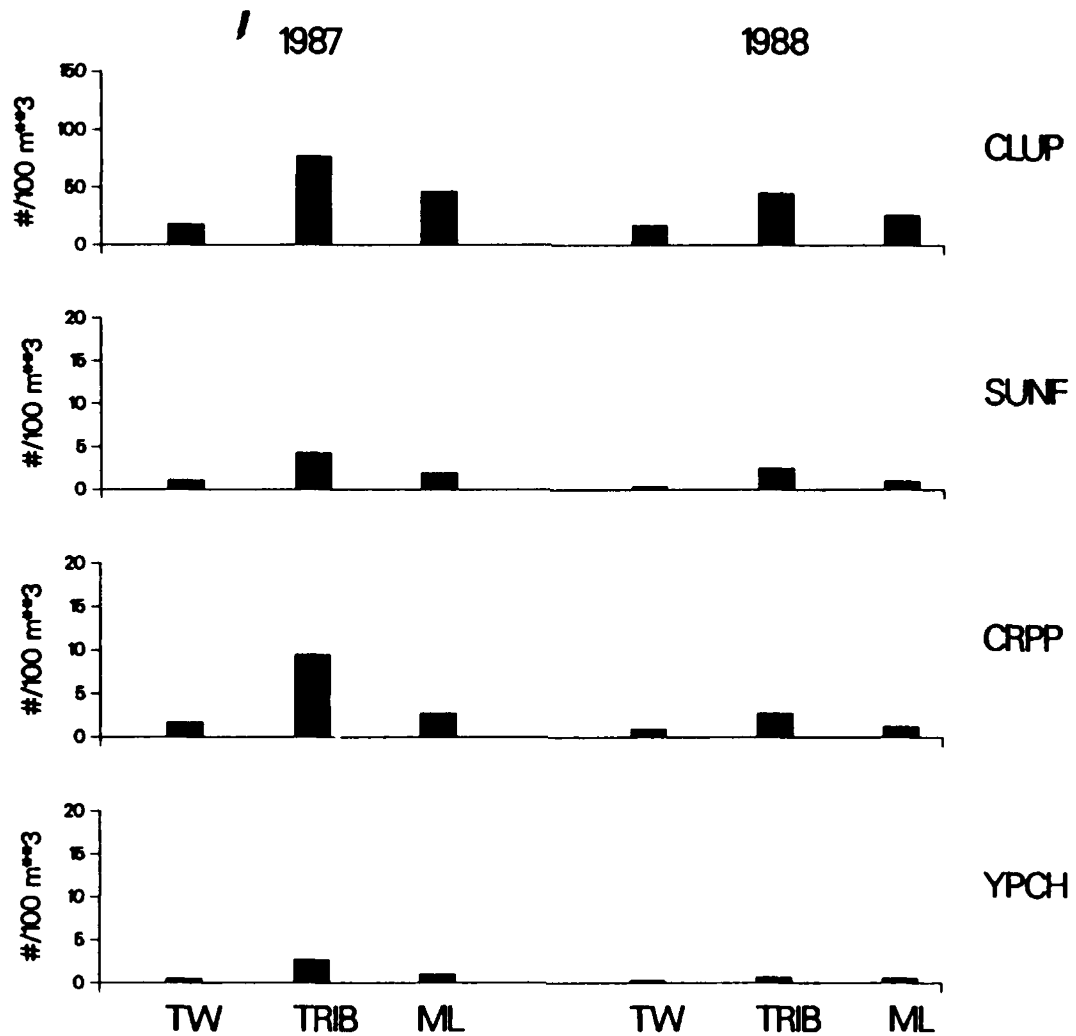

Figure 26. Densities of larval fishes at tailwater (TW), tributary (TRIB), and main-lake (ML) stations in JST Lake, 1987-88, all sample dates pooled

SESSION II: J. STROM THURMOND TAILWATER INVESTIGATIONS

HYDRAULIC ANALYSES OF J. STROM THURMOND RESERVOIR HEADWATERS

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Introduction

The SAS manages water resources within the Savannah River Basin by the operation of three reservoir projects: HL, RBR Lake, and JST Lake, formerly Clarks Hill Lake. The RBR Dam, situated between HL and JST, is the most recently completed project. The RBR Dam was constructed in the headwaters of JST Lake at Trotter Shoals. This project currently includes a hydroelectric power plant consisting of four vertical-axis, fixed-blade Francis turbines rated at 75 mw each with a net head of 145 ft at maximum conservation pool and a total discharge of 30,000 cfs. The SAS is in the process of adding pumped-storage capability to the RBR Project. The addition of four 75-mw pump/turbines will double the hydroelectric generation capacity while enabling the recharge of RBR Lake from the adjacent JST Lake. The completion of the Richard B. Russell powerhouse will result in a total capacity generation discharge of 60,000 cfs and pumping capacity of 24,800 cfs. The investigation reported herein examined the impacts of increasing the generation and pumpback flows from the RBR project. Of particular concern was the interaction of flows with the downstream channel, which is constricted by sand deposits.

Project Description

Releases from the RBR Project flow into JST Lake, located directly downstream. The RBR Project consists of a powerhouse (625 ft wide) adjacent to the Georgia shore with a 600-ft-long spillway section adjacent to the South Carolina shore. The tailrace was constructed on a 1:5 slope for a distance of 175 ft downstream of the powerhouse and transitions into the natural head-waters of JST. The channel width of the afterbay region remains relatively constant within one-half mile of the dam with an average thalweg elevation of

just under 300 ft.* The channel bed in this region is highly irregular because of material remaining from the construction phase of the project. Beyond the half mile mark, the channel begins to widen accompanied by a rapid rise in the average channel-bed elevation. Much of this region becomes dry as the JST pool drops during low-flow periods. The main channel transitions into a sand flat at the mouth of the first major embayment in JST. This shallow sandbar extends to about 1.25 miles south of the dam, where the presence of a main channel reappears and the thalweg elevation returns to under 300 ft. A bed elevation contour map of the study area is shown in Figure 27.

Purpose and Scope of Work

The purpose of this study was to identify whether adverse hydrodynamic conditions will develop upon the completion of the RBR powerhouse during capacity generation and pumpback. In the event adverse hydraulic conditions significantly impact project operation, corrective measures were to be identified.

The channel features in the headwater regions of JST may have a significant influence on the operation of the completed powerhouse both in generation and pumpback modes. The potential for severe tailwater pool drawdown during pumpback operation may occur if upstream flow is constricted sufficiently in JST. The capacity of the pumps may be reduced significantly if tailwater drawdown is experienced, thereby increasing the time required to pump back a specified volume of water. The potential for cavitation damage to the pump turbine also increases as tailwater stages drop. During generation, the shoal region may result in backwater effects raising the tailwater pool that reduces the potential energy available for power production. Given that such hydraulic conditions would impair the operation of the completed powerhouse, the SAS is prepared to consider increasing the conveyance of the downstream channel.

The approach taken for the study reported herein was to first assess the existing flow fields associated with generation discharges. The second step of this study involved the use of observed flow field data to develop a numerical model of the afterbay region of the RBR Project for the prediction of hydraulic conditions at the completion of the project. Flow conditions

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* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

during full conventional generation (60,000 cfs) and full pumpback (24,800 cfs) at tailwater el 330, 325, 320, 315, and 312 ft were modeled for the existing afterbay channel configuration. A one-dimensional (1-D) steady-state model entitled HEC-2 was used to determine whether adverse hydraulic conditions should be expected.

Existing Flow Conditions

Depth-averaged steady-state velocities for two independent flow events were monitored at four transects in the afterbay of the RBR Dam using a current meter. The transects were located downstream of major changes in the channel cross section normal to the direction of flow. Transect A was established at the buoy line approximately 750 ft downstream of the powerhouse. The next three transects, B, C, and D, were located downstream of the dam approximately 2,250 ft, 4,250 ft, and 5,700 ft, respectively. Station markers were located at equal intervals across each transect to establish monitoring stations.

Constant hydropower releases were requested from SAS during the period of this study, which was conducted the week of 9 February 1987. A low-flow event consisting of releases of 8,900 cfs was scheduled for the first 2 days of the study, while a higher flow event of 12,000 cfs was scheduled for the final 2 days. Tailwater pool elevations during this study were near normal pool and ranged from 329.8 to 330.6 ft. Monitoring far-field flow characteristics was delayed 1 hr after the initiation of power generation to allow steady-state conditions to develop.

Observations during this investigation indicated shifting flow distributions from transect to transect. The flow patterns observed at Transect A indicated downstream flow along the Georgia bank and upstream flow along the South Carolina bank. This flow feature indicates a region of recirculation residing downstream of the spillway during generation discharges. The flow shifted to the South Carolina side of the channel at Transect B. This flow redistribution was attributed to the remains of a cofferdam located adjacent to the Georgia bank. The flow moved back to the Georgia side of JST on Transect C because of a shallow sandbar located predominantly against the South Carolina bank. Velocities were significantly reduced on Transect D because of the abrupt expansion in the channel. The velocities were skewed

toward the Georgia bank at this monitoring station. No measurable fluctuation in the tailwater stage was observed during these generation flows.

Historical records from the RBR power plant indicated the presence of increased tailwater stages during project releases (tailwater stage setup). The tailwater stage increase is directly proportional to the generation discharge and inversely proportional to the initial tailrace stage. Substantial tailrace stage fluctuations during project releases are more evident during lower pool conditions in JST. Furthermore, higher project releases will result in greater tailrace setup, the degree of which is largely dependent on initial stage conditions. The power plant records of tailrace stages and project releases listed in Table 4 reflect these relationships. A maximum setup of about 5.6 ft was observed on 18 November 1986 with initial tailwater elevation of 316.65 ft during a 25,600-cfs release. The maximum setup over a month later on 25 December was only about 1.2 ft for an initial tailwater elevation of 322.4 during a 25,300-cfs release.

Table 4

Richard B. Russell Power Plant Records of Project Release and Tailwater Stage

	18 November 1986		25 December 1986	
Time hr	Flow cfs	Tailwater El ft	Flow cfs	Tailwater El ft
1700	0	316.80	0	322.46
1800	0	316.80	6,390	322.66
1900	22,130	321.70	23,150	323.60
2000	25,630	322.40	25,300	323.65
2100	18,720	321.10	10,470	322.48
2200	3,960	317.23	960	322.20
2300	3,960	317.23	0	322.20
2400	0	316.65	0	322.20

Numerical Model Calibration

The HEC-2 computer program was used to study the influence of channel features in the JST headwaters on water-surface profiles subject to various tailwater pool conditions during capacity pumpback and generation. The model was developed for calculating the water-surface profiles for steady, gradually varied flow in channels. The program solves the 1-D energy equation using the Standard Step Method subject to frictional resistance as determined by

Manning's equation. The program can handle both supercritical and subcritical flow provided that the flow is 1-D and invariant in time. Channel features were expected to become increasingly influential on the resultant water surface profiles as tailwater conditions approached minimum pool (312 ft).

The data required to simulate flow conditions with the HEC-2 program include channel geometry and energy loss coefficients. The channel geometry was obtained from hydrographic surveys conducted by SAS in the JST headwater regions during 1986 and 1987. The 1987 survey included cross-sectional information from the project to approximately 1 mile downstream. The transects were spaced on about 250-ft intervals for the first 0.5 mile. Channel geometry beyond 1 mile from the project was taken from the 1986 survey. The 1986 survey extended the description of JST an additional 1.4 miles with transects spaced approximately on 500-ft intervals.

The Manning's n coefficient is generally determined by reproducing a known hydraulic grade line throughout the study region. Stage information within the study reach is limited to the powerhouse records of hourly tailwater pool during conventional generation. During the field study investigation, the steady generation of about 12,000 cfs at normal pool conditions resulted in no significant fluctuation in the tailwater pool. The determination of the frictional resistance in the form of the Manning's n was therefore based upon modeling events observed during the 1986 calendar year. A total of 19 separate flow events with various initial tailwater stages and generation flow rates were modeled. The frictional resistance in the channel was adjusted by comparing the observed tailwater setup with the calculated tailwater setup. The selected Manning's n value of about 0.03 was chosen as providing the best fit to the observed data for existing channel conditions. The contraction and expansion loss coefficients used in this study were 0.1 and 0.3, respectively.

Results from the field study revealed regions of recirculation during generation flows. This flow feature was introduced into the 1-D simulations by defining an effective flow area on cross sections near the dam. These flow characteristics were not expected to be present during capacity pumpback conditions.

Numerical Model Simulation of Existing Channel

Capacity generation of 60,000 cfs was simulated using the HEC-2 model assuming JST pool elevations of 330, 325, 320, 315, and 312 ft. The model determined the resultant tailrace pool level that would provide conveyance of this flow rate during steady-state capacity generation conditions. Steady-state flow conditions resulting from generation flows throughout the study area may not be a frequent occurrence because the hydroelectric generation at RBR is scheduled to meet peak power demands. Flow conditions within 1 mile of the dam should, however, approach steady-state conditions within 1 hr of capacity generation based upon time-of-travel estimates for existing conditions. These simulations provide an opportunity to evaluate backwater effects expected during certain flow conditions. Any pooling of water in the tailrace region would reduce the effective head available for hydroelectric generation. The water-surface profiles for these five simulations are illustrated in Figure 28.

The backwater effects for capacity generation became significant when JST levels dropped below el 25 ft. When reservoir levels were above el 325 ft, the existing reservoir channel could convey the 60,000-cfs release without significantly influencing the water surface. As the reservoir level dropped below el 325 ft, the tailrace pool elevation remained almost constant because of the downstream shift in flow control.

The average channel velocities during capacity generation can be expected to exceed 2 fps throughout much of the study area for all pool conditions modeled. For normal pool conditions, the average cross-sectional velocities were greater than 2 fps within a mile of the RBR Dam. As the JST water levels dropped, the corresponding velocities increased significantly, as shown in Figure 29. These high-velocity conditions in the headwater region of JST probably would cause significant local scour. Degradation of the channel bed in this region would reduce channel velocities until a stable channel alignment was reached. Geological borings of the reservoir bed have revealed an erosion-resistant bedrock located well beneath the thalweg of the existing channel. Estimation of the sediment transport throughout the study area was beyond the scope of this study.

The HEC-2 model also was used to identify the minimum JST elevation sufficient to convey flow to the pumping station during pumpback. These

simulations provide an opportunity to evaluate the degree of drawdown to be expected during certain flow conditions. Drawdown will cause a greater use of resources to pump back a given volume of water.

The capacity pumpback simulations for pool el 330 and 325 ft had only a minor effect on tailrace stages. The effects of drawdown in the tailrace area became significant only when JST levels dropped below el 322 ft. Under these flow conditions, water was pumped out of the tailrace region faster than it could be replaced by water from JST, resulting in tailrace drawdown. Under some conditions, the tailrace pool would continue to drop until it became unfeasible to operate in a pumping mode. The water-surface profiles for these five simulations are illustrated in Figure 30.

The average channel velocities within a mile of the dam during capacity pumpback exceed 2 fps for JST pool levels below el 325 ft. The maximum velocity more than doubled when the tailrace stage was lowered to el 320 ft, as shown in Figure 31. Continuous drawdown of the tailrace pool is anticipated for JST pool conditions approaching minimum levels.

Numerical Model Simulation with Channel Improvement

The anticipated hydraulic conditions associated with capacity pumpback and generation flows with the existing channel configuration will significantly limit project operation when JST levels drop below 322 ft. Channelizing the study area would provide additional flow conveyance required to maintain suitable flow conditions for these tailwater conditions. The following channel design parameters are required to fully define alternative channel improvements: bottom width, invert elevation, channel orientation, and channel side slope. The channel design that closely matched the existing width of JST within the study area is a trapezoidal channel with a bottom width of 800 ft and a side slope of 1 on 5. A design channel width narrower than 800 ft requires a greater volume of excavation for the same channel conveyance. Channel invert elevations ranging from 298 to 310 ft were investigated to study the trade-off between flow conditions and excavation volume. The channelization would begin about 800 ft downstream of the project and continue for a little over 1 mile. The channel improvement is centered between the Georgia and South Carolina shores in the northern half of the excavation region. The southern end of the channel improvement tends towards

the Georgia shore in order to tie into the existing channel as shown in Figure 32.

All proposed channel improvements resulted in near level pool conditions for JST levels greater than or equal to 320 ft during capacity pumpback. As lake level approaches minimum pool conditions, differences in the resultant flow fields associated with the various channel improvements appear as shown in Table 5. A maximum drawdown of 5 ft is required for the 310-ft invert channel to deliver the capacity flow to a tailrace pool elevation of 312 ft. For this channel configuration, JST levels below 317 ft would result in tailrace pool elevations less than 312 ft. In contrast, the 298-ft channel improvement will maintain minimum tailwater pool conditions for JST levels as low as 313 ft. The water-surface profiles for capacity pumpback with the 307-ft channel improvement is shown in Figure 33.

Table 5

Summary of Flow Field Simulations Under Existing and Improved Channel Configurations During Capacity Pumpback (Q = 24,800 cfs)

TW	Channel Bed Configuration					
Level ft	Existing JST El	Invert 298 JST El	Invert 300 JST El	Invert 305 JST El	Invert 307 JST E	Invert 310 JST El
330	330	330	330	330	330	330
325	325.5	325	325	325	325	325
320	322.5	320	320	320	320	320.5
315	322	315	315.5	316	316	317.5
312	322	313	313.5	314	315	317

Velocity fields associated with the five channel designs are similar for JST levels ranging from 330 to 325 ft for capacity pumpback conditions (Table 6). At el 325 ft, the maximum velocity modeled in any of the channel improvement scenarios was about one-half of the maximum velocity in the existing channel. The maximum channel velocities increase at a greater rate in the shallower channels for decreasing depth of flow. A maximum velocity of over 4 fps was modeled for capacity pumpback condition at minimum pool conditions. The velocity profiles for capacity pumpback with the 307-ft channel improvement are shown in Figure 34.

During capacity generation, all proposed channel improvements resulted in near level pool conditions for JST levels greater than or equal to 325 ft. At a JST level of 320 ft, the tailwater setup ranged from 2.5 ft for the

Table 6

Summary of Flow Field Simulations Under Existing and Improved Channel Configurations with a Maximum Velocity During Capacity Pumpback of 24,800 cfs

JST Level ft	Existing Max. Vel	Invert 298 Max. Vel	Invert 300 Max. Vel	Invert 305 Max. Vel	Invert 307 Max. Vel	Invert 310 Max. Vel
330	1.4	1.0	1.0	1.0	1.0	1.0
325	2.8	1.3	1.3	1.3	1.4	1.4
320	7.0	1.8	1.8	1.85	2.1	2.7
315	12.0	2.8	2.8	2.8	3.5	5.2
312	12.6	4.2	4.2	4.2	4.8	8.1

310-ft channel improvement to level conditions for the 298-ft channel improvement as shown in Table 7. As the level approaches minimum pool conditions,

Table 7

Summary of Flow Field Simulations Under Existing and Improved Channel Configurations at Various Tailwater Pool Elevations During Capacity Generation of 60,000 cfs

	Channel Bed Configuration					
JST Level ft	Existing TW El	Invert 298 TW El	Invert 300 TW El	Invert 305 TW El	Invert 307 TW El	Invert 310 TW El
330	331	330	330	330	330	330
325	327	325	325	325	325	325
320	326.5	320	320.5	321	322	322.5
315	326	317	317	319	320	322
312	326	316	316	318.5	320	322

the tailwater pool setup reaches a maximum for each channel configuration. The existing channel bed would experience 14 ft of tailwater setup during capacity generation flow conditions at minimum level conditions. The tailwater setup for the channel improvement scenarios ranged from 10 ft for the 310-ft channel improvement to 4 ft for the 298-ft channel improvement. The water-surface profiles for capacity generation with the 307-ft channel improvement are shown in Figure 35.

The maximum velocity during capacity generation will be reduced up to 50 percent if a channel improvement is implemented. The variation of the

maximum velocity during generation conditions is relatively small between the different channel designs.

The maximum velocity in the 298-ft channel improvement is generally 1 to 2 fps less than the maximum velocity in the 310-ft channel design as shown in Table 8. The velocities in the improved channel during capacity generation at minimum pool conditions may still be large enough to cause signifcant channel

Table 8

Summary of Flow Field Simulations Under Existing and Improved Channel Configurations with a Maximum Velocity During Capacity Generation of 60,000 cfs

	Channel Bed Configuration					
JST Level ft	Existing Max. Vel	Invert 298 Max. Vel	Invert 300 Max. Vel	Invert 305 Max. Vel	Invert 307 Max. Vel	Invert 310 Max. Vel
330	3.4	2.2	2.3	2.5	2.5	2.6
325	6.5	2.9	2.9	2.95	3.2	3.8
320	6.5	4.0	4.1	4.2	4.7	5.8
315	12.6	5.3	5.3	5.3	5.7	6.7
312	12.6	6.7	6.7	6.7	7.0	7.7

degradation. The velocity profiles for capacity generation with the 307-ft channel improvement are shown in Figure 36.

The estimated excavation volume of the five channel scenarios investigated in this study were as follows: Invert 298, 3.2 million cubic yards; Invert 300, 2.8 million cubic yards; Invert 305, 1.85 million cubic yards; Invert 307, 1.5 million cubic yards; and Invert 310, 0.98 million cubic yards. The removal of material required to implement the channel improvement scenarios is distributed nearly uniformly along the impacted area.

Conclusions and Recommendations

Field and modeling studies show that backwater effects during capacity generation will raise tailwater stages and reduce effective head available for hydropower generation when JST levels fall below el 325 ft in the existing channel configuration. There is a high probability that some bed material will scour during capacity generation at low levels. The extent of sediment transport during capacity generation flows was outside the scope of this study. Sediment transport characteristics in the headwaters of JST should be

investigated further because of implications with the proposed dredging plans and subsequent operation of pumped storage. The potential may exist to promote significant scour in portions of the headwater regions of JST, thereby reducing the extent of or eliminating the need for dredging.

The existing bed configuration will significantly influence flow conditions during capacity pumpback events. When JST levels drop below el 322 ft, the tailrace will begin to experience significant drawdown. As the JST levels approach minimum pool, the location of flow control will change, resulting in a continuous depletion of water in the tailwater. The resultant drawdown may proceed to the point of impacting pumpback operations. These preliminary results will need to be re-evaluated if significant bed movement takes place during project operation.

An increase in conveyance of the channel leading to the RBR powerhouse can be achieved through channel excavation. The recommended channel improvement consists of a 1-mile-long trapezoidal channel with a bottom width of 800 ft, and 1 on 5 side slopes. The identification of acceptable flow conditions during project operation will lead to a selection of the design channel invert elevation. Channel improvement would require moving from 1.0 to 3.2 million cubic yards of material from the study area.

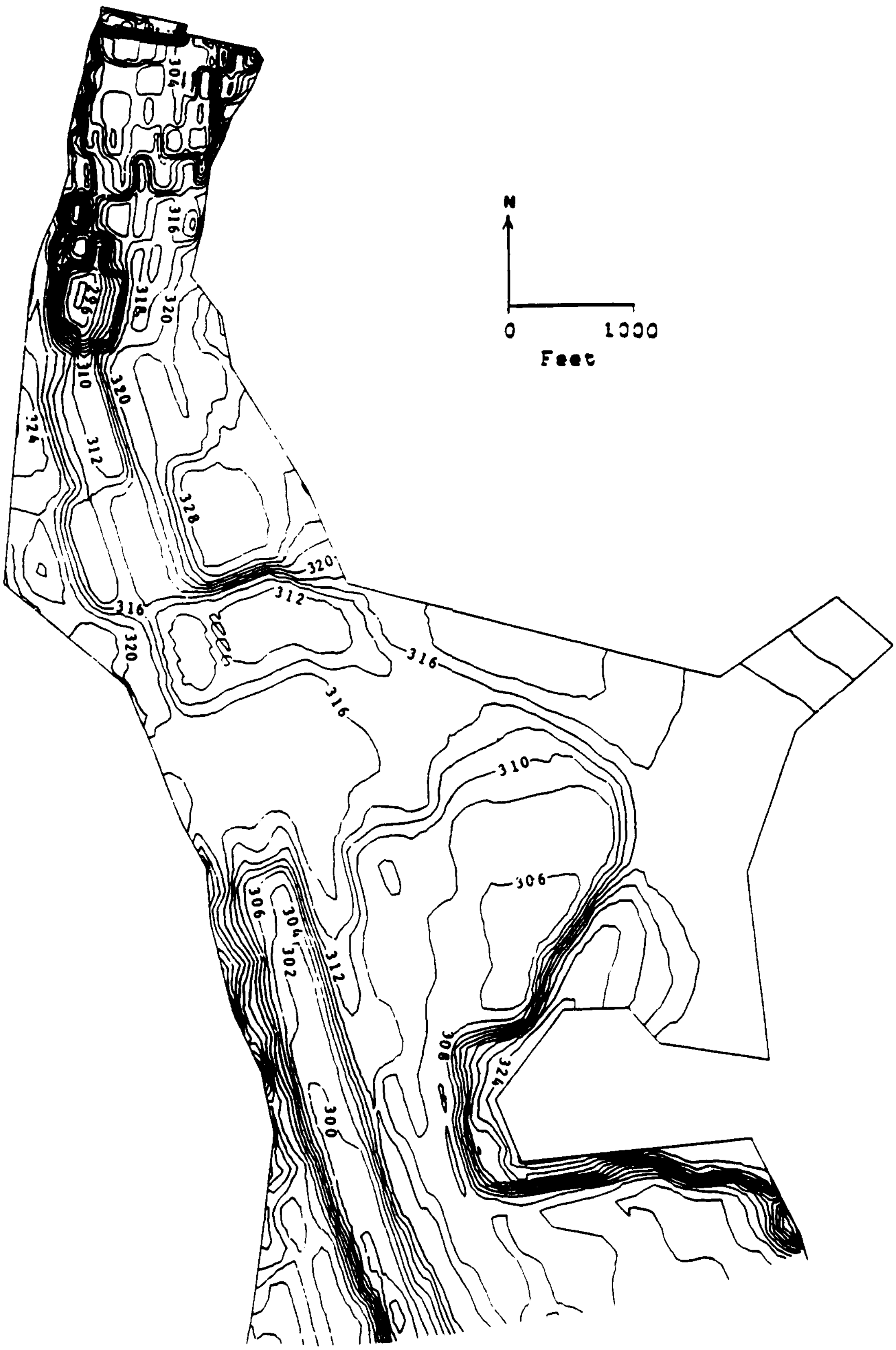

Figure 27. Contour map of JST Lake

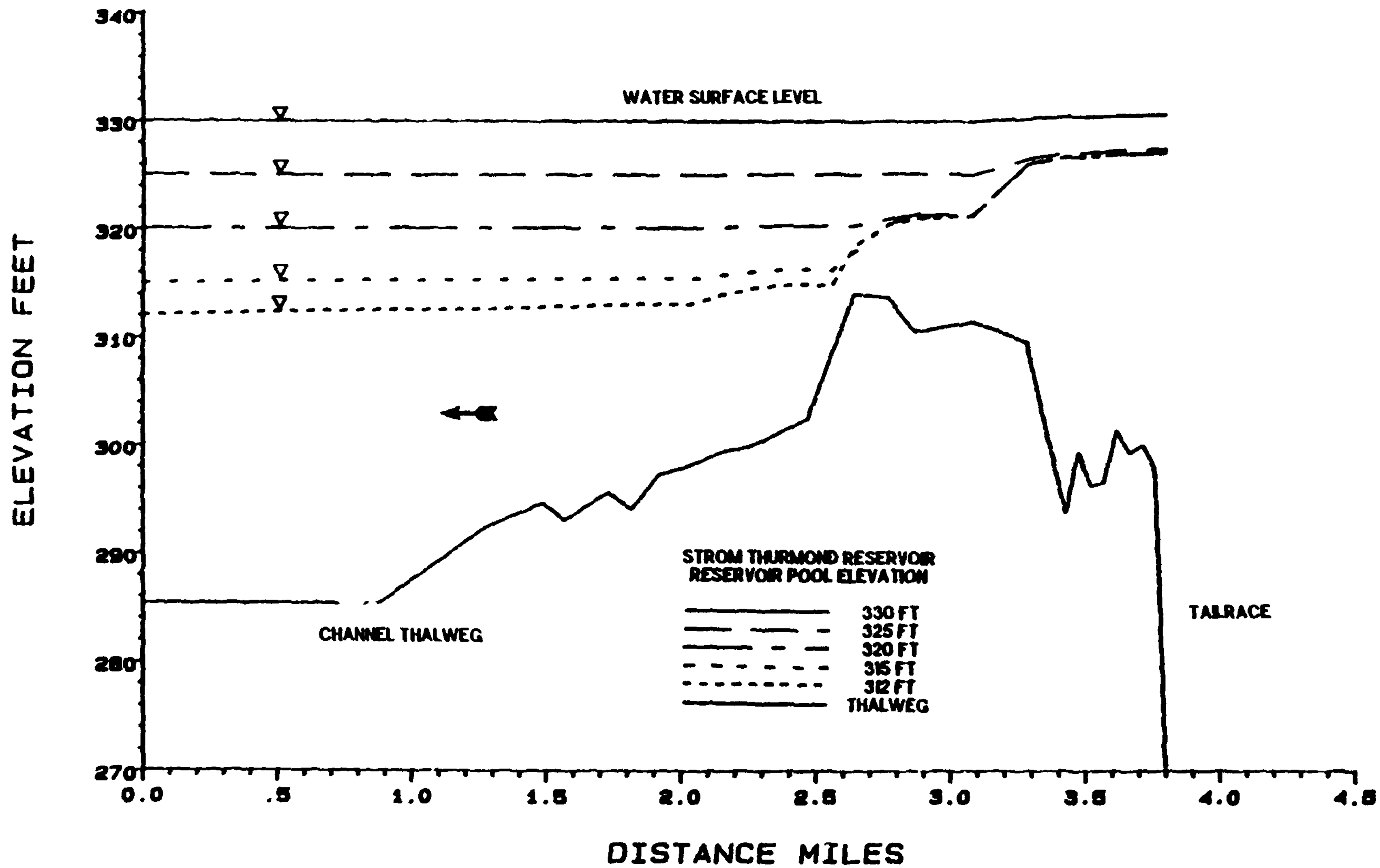

Figure 28. Water-surface profiles for JST Lake at capacity generation of 60,000 cfs

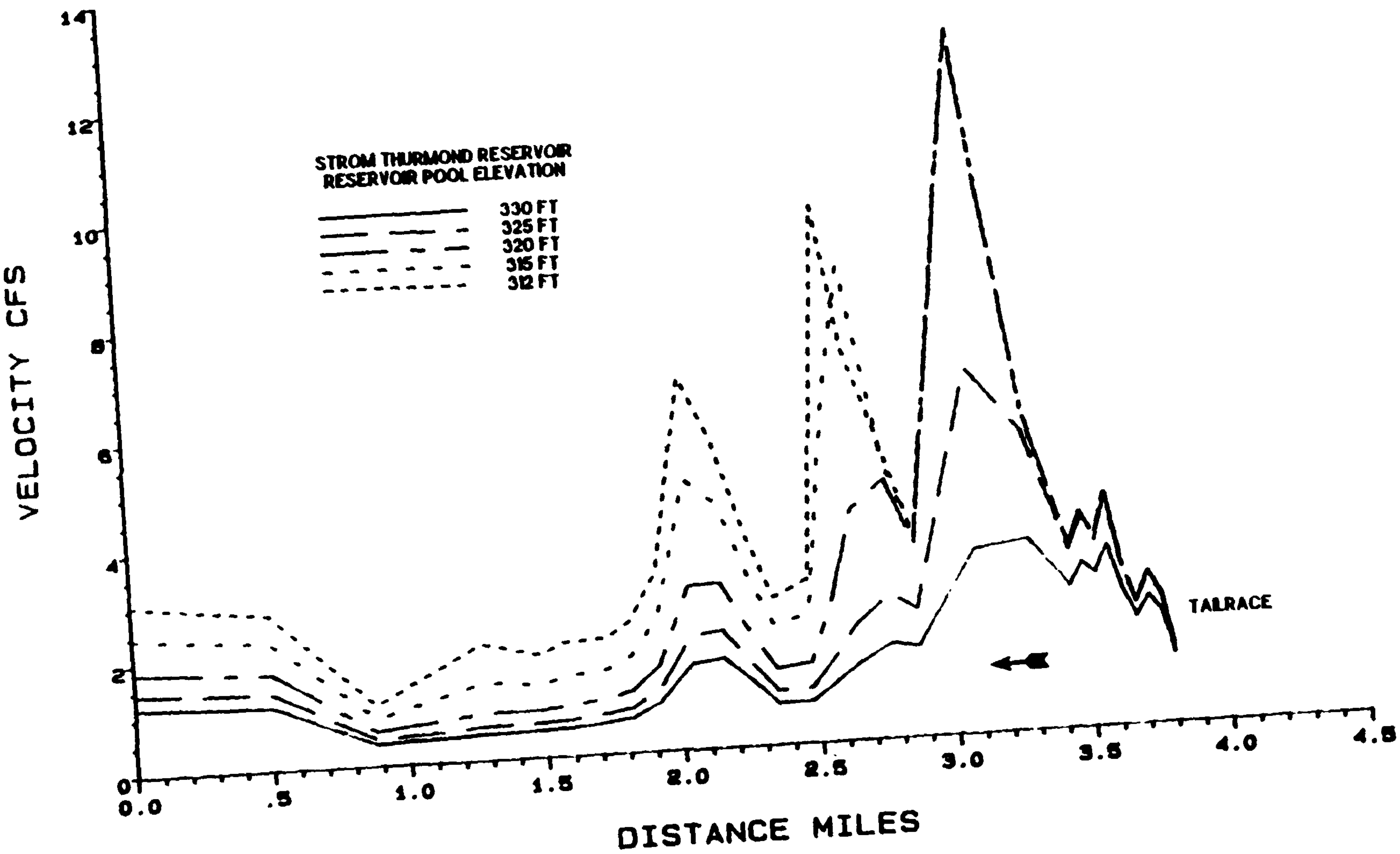

Figure 29. Velocity profiles for JST Lake at capacity generation of 60,000 cfs

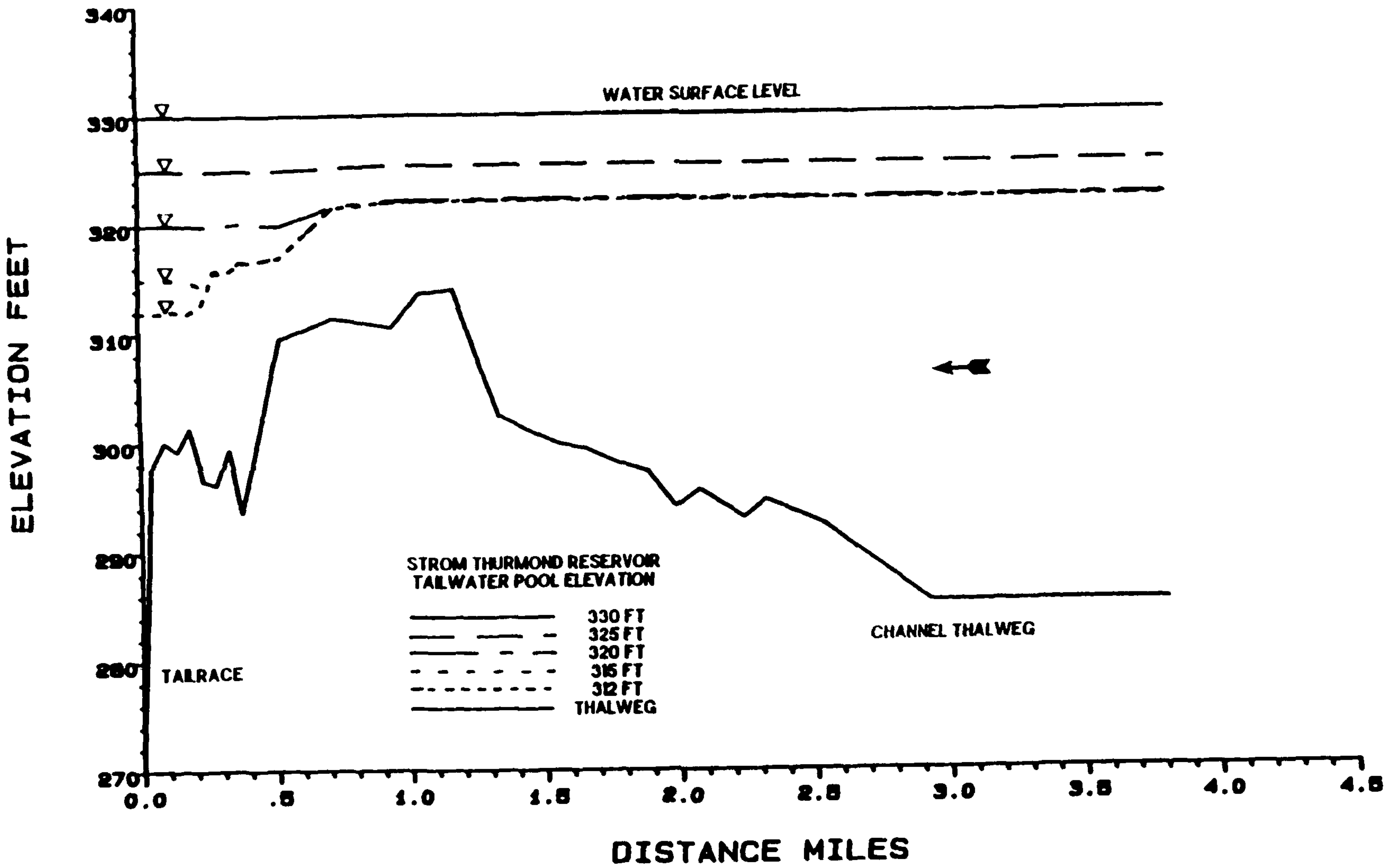

Figure 30. Water-surface profiles for JST Lake at capacity pumpback of 24,800 cfs

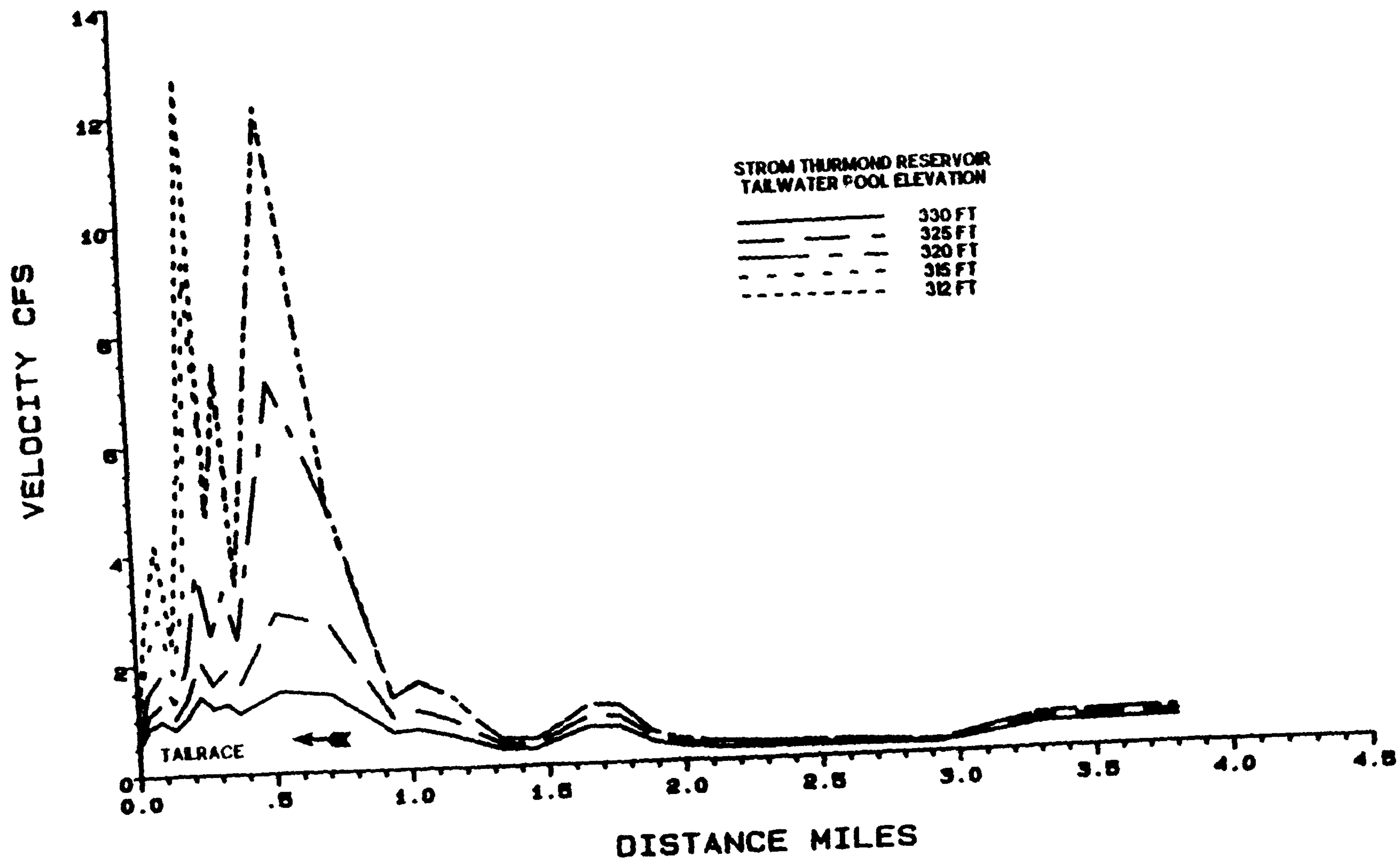

Figure 31. Velocity profiles for JST Lake at capacity pumpback of 24,800 cfs

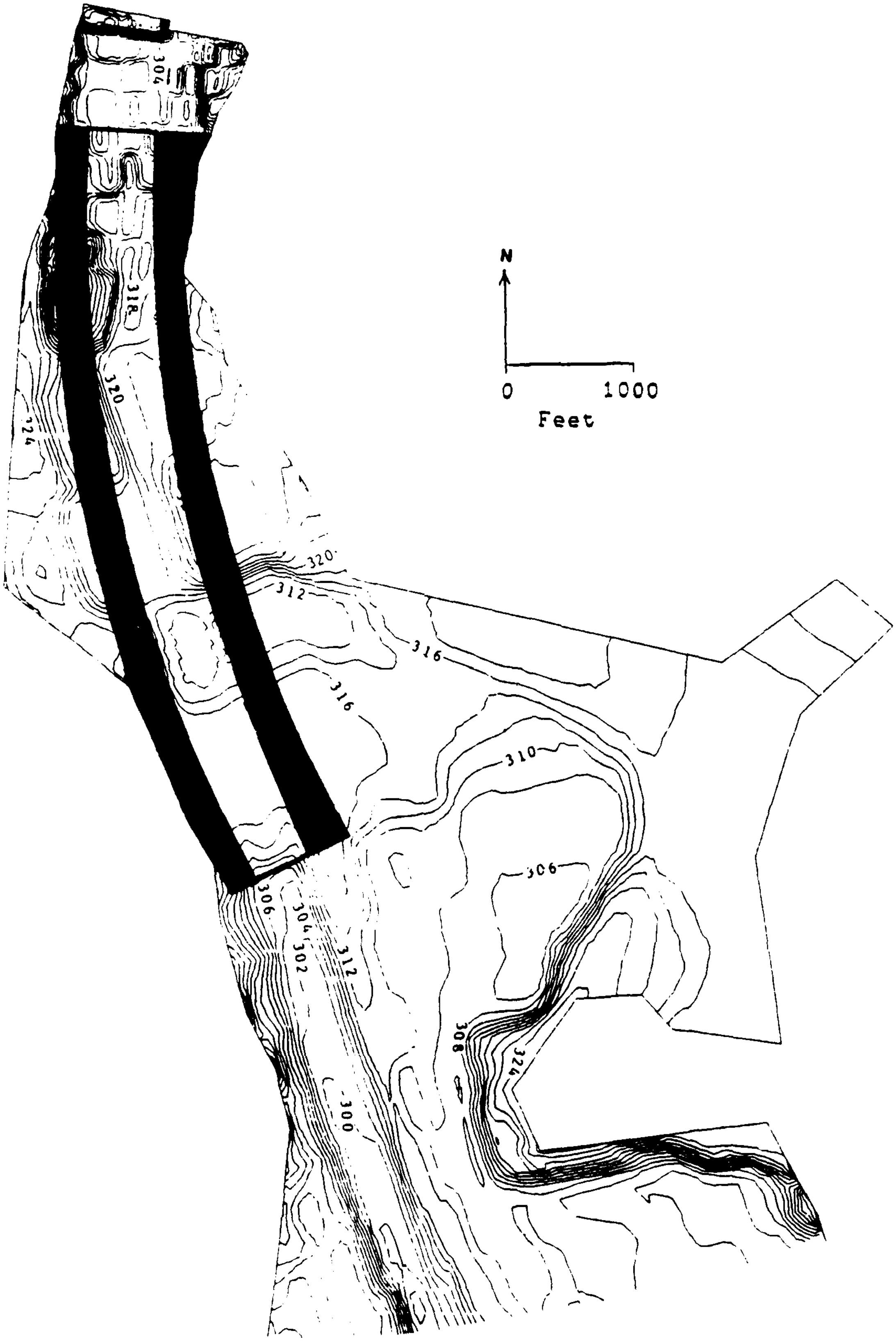

Figure 32. Proposed channel improvement below RBR Dam

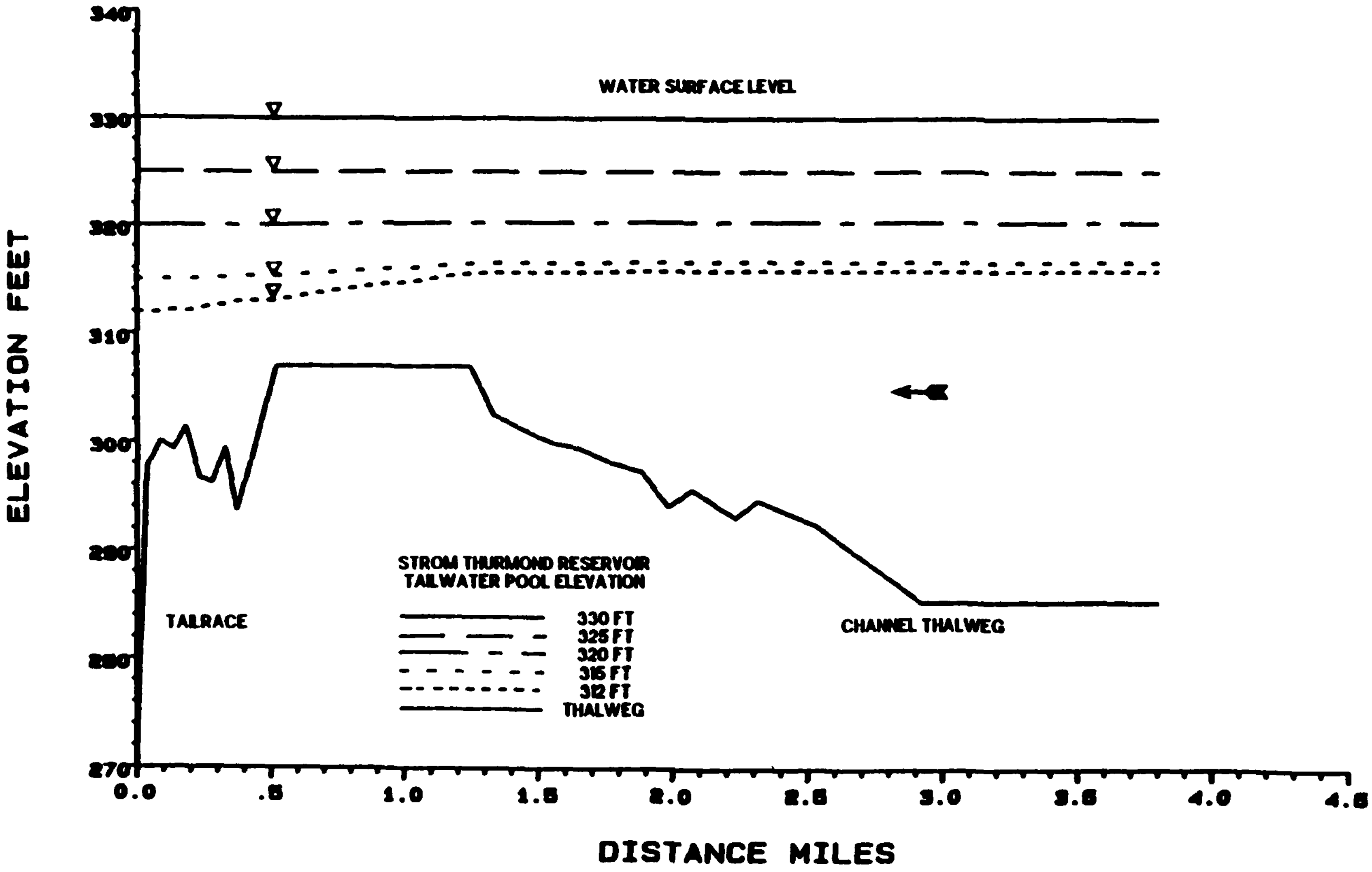

Figure 33. Water-surface profiles for JST Lake pumpback of 24,800 cfs after excavation to 307 ft

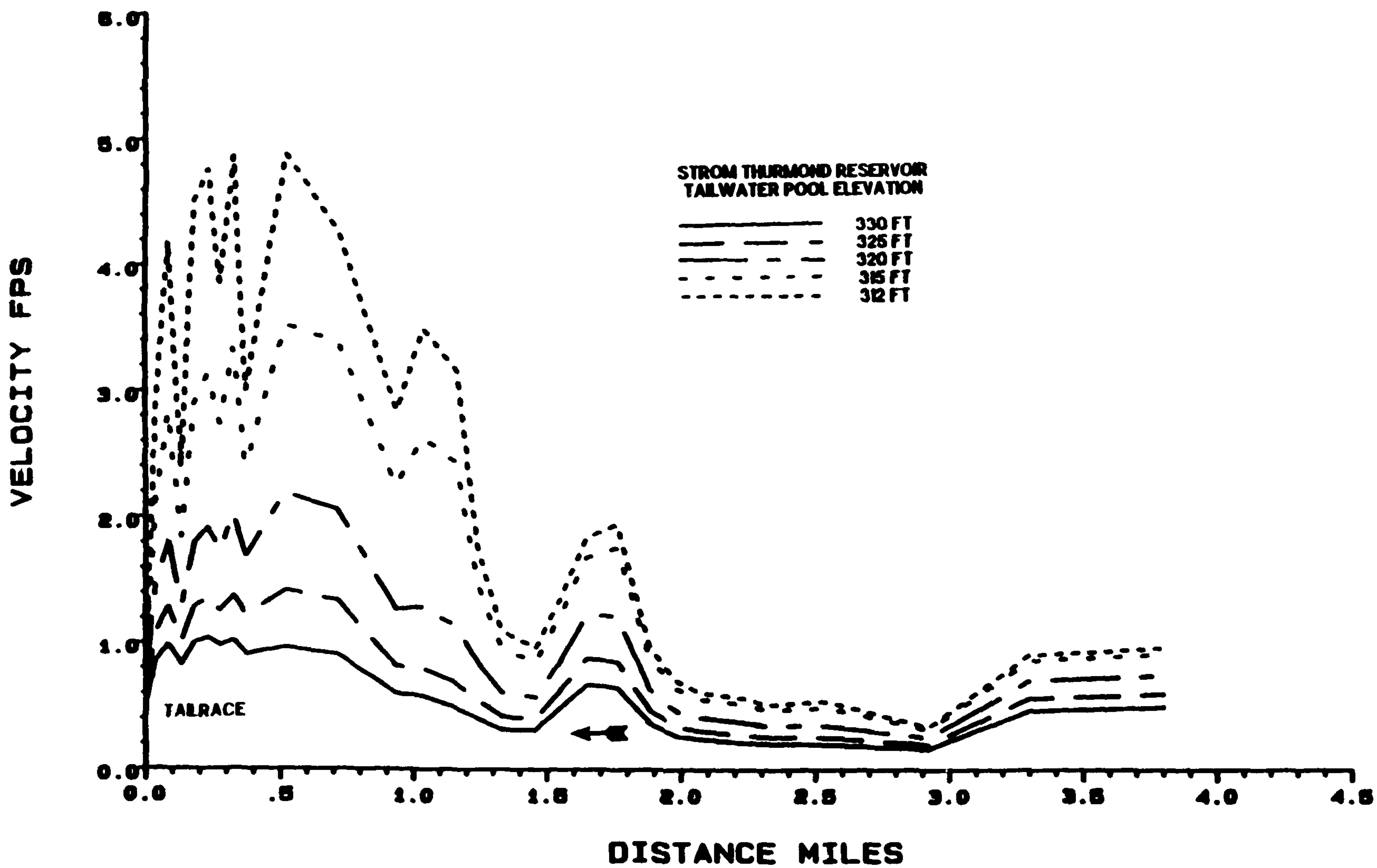

Figure 34. Velocity profiles for JST Lake pumpback of 24,800 cfs after excavation to 307 ft

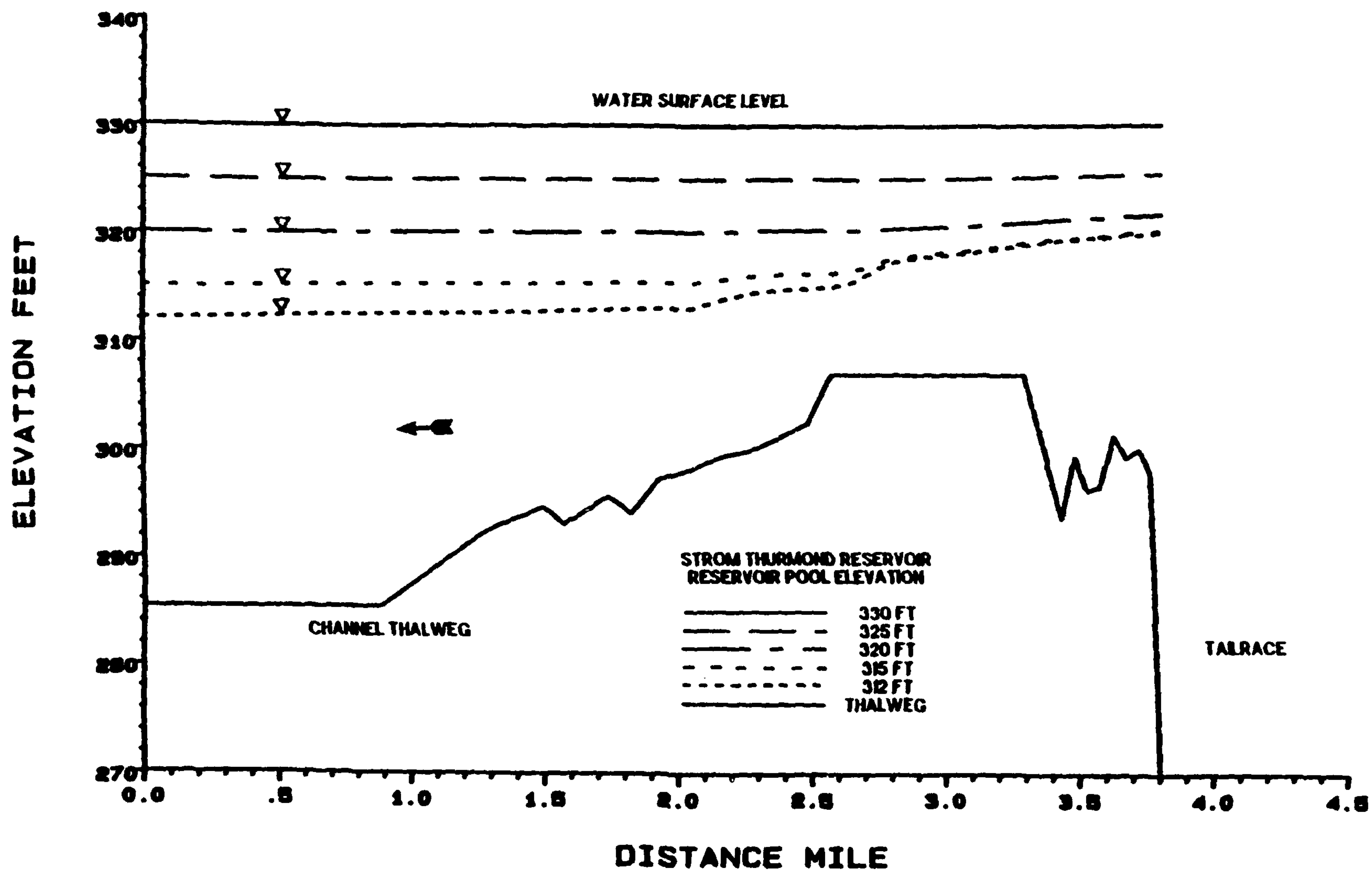

Figure 35. Water-surface profiles for JST Lake generation of 60,000 cfs after excavation to 307 ft

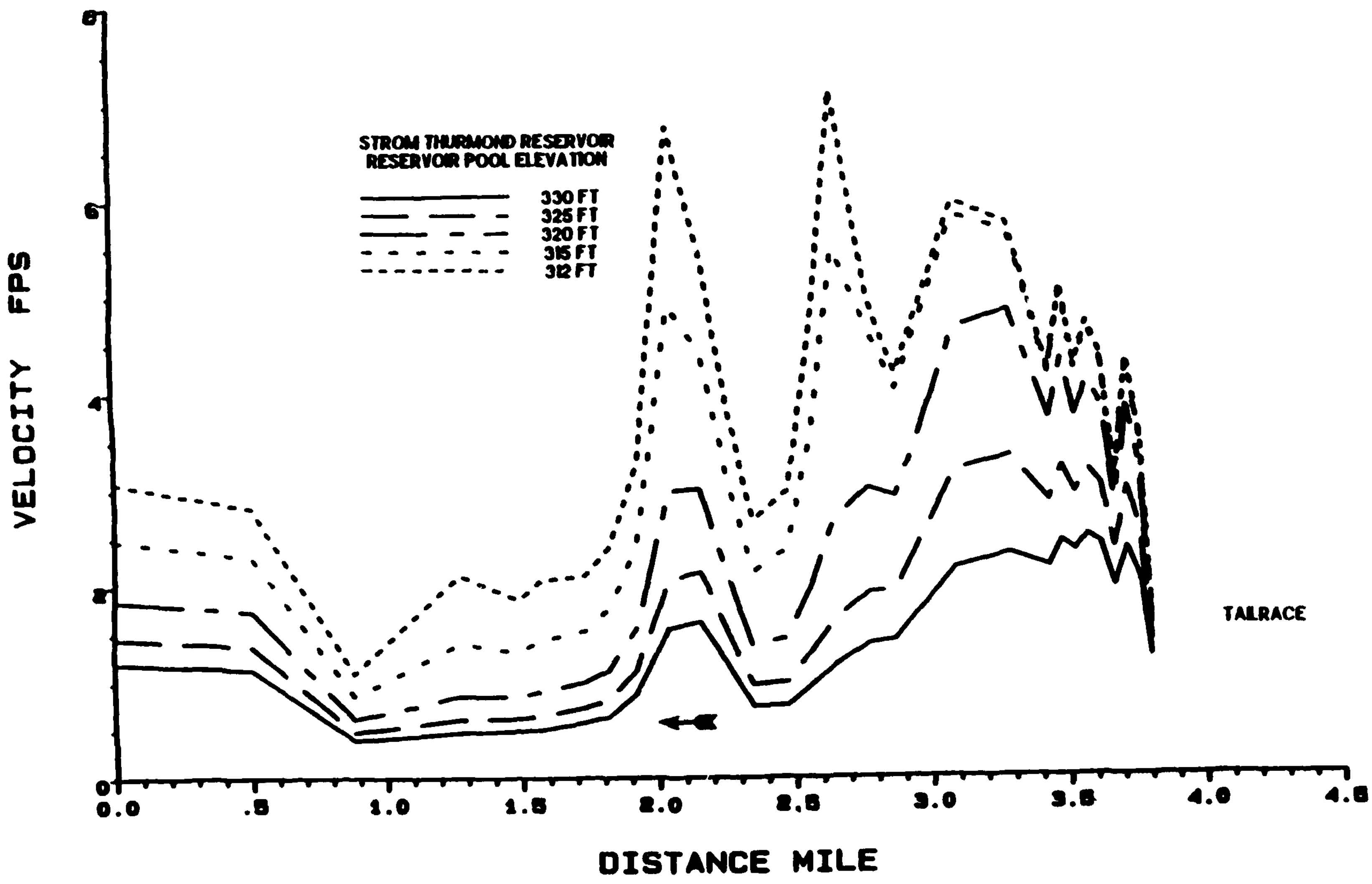

Figure 36. Velocity profiles for JST Lake generation of 60,000 cfs after excavation to 307 ft

NEAR-FIELD SPATIAL AND TEMPORAL FISH DISTRIBUTIONS

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Introduction

Sampling has been conducted in the tailwater area below RBR Dam since February 1986 to determine the potential of fish entrainment during pumpback operations. The area extending from the dam to about 3.1 miles downstream in JST Lake has been sampled intensively with hydroacoustic gear, gill nets, electrofishing, ichthyoplankton gear, and purse seines. The purpose of this presentation is to provide an overview of results obtained by electrofishing and gill netting. Specific questions to be addressed include:

a. What are the spatial patterns in abundance of fish throughout the tailwaters?

b. What are the seasonal trends in the tailrace?

c. What species of fish occur near the draft tubes?

Methods

Stations 1, 2, and 3 comprise what are termed "tailwater" sampling stations. Station 1, located immediately below RBR Dam, is termed the "tailrace" area. These three stations were sampled by routine gill netting from February 1986 through September 1988, electrofishing from July 1986 through September 1988, and specialized gill netting from October 1987 through September 1988.

In the routine gill netting, samples were collected monthly (sometimes twice per month) using 45.72-m monofilament nets that had six 7.62-m panels of 25.4-, 38.1-, 50.8-, 63.5-, 76.2-, and 88.9-mm mesh webbing. On each sampling occasion, two nets were set overnight on the bottom of the spillway side at Station 1. On many occasions, hydropower releases occurred during sampling, making it impossible to set nets on the powerhouse side. At Stations 2 and 3, four nets were used. Two were set near the bank perpendicular to the

shoreline, and two were set offshore. All catch rates were expressed as kilograms per net.

Electrofishing samples also were collected monthly at night after any hydropower releases had ceased. At Station 1, electrofishing efforts covered 305-m transects immediately below the dam on both the Georgia and South Carolina bank and a 305-m transect along the dam itself. Efforts at Stations 2 and 3 included three 152.4-m transects at each site. Results were expressed as the catch rate in kilograms per hour.

Supplemental tailrace gill netting was begun in October 1987 and conducted monthly thereafter to obtain better information on species abundance near the draft tube outlets on the powerhouse side of the dam. Each sampling consisted of two nets set on the bottom on the powerhouse side plus two nets set in the same location as the "routine" samples on the spillway side. These sets were made during generation "moratoria" (i.e., no hydropower releases).

Results

Temporal trends

Catches from routine gill netting are summarized for all species combined in Figure 37. At Station 1, catches tended to be highest in spring (April-June) and lowest during October. Seasonal trends were not as apparent at Stations 2 and 3. Some of the variation in seasonality may have been caused by differences in water level. Both 1986 and 1988 were extreme low-water years.

Electrofishing catch rates were variable but showed little, if any consistent seasonality (Figure 38). Peaks in biomass occurred because of the inclusion of one or two large individuals of species that were rarely sampled rather than increases in fish abundance.

Spatial patterns

Catches of the 10 most abundant species in routine gill netting were often higher at Station 1 than at Stations 2 and 3 (Figure 39). These included hybrids, white bass, silver redhorse, spotted sucker, and carp-suckers. Gizzard shad and longnose gar were most abundant at either Station 2 or 3, and catches of striped bass and common carp were similar at all locations. The higher catches of sauger at Station 2 reflect the availability of

preferred habitats in the vicinity of the sampling location (see "Telemetry" by Welch, this report).

Electrofishing catches of the eight major species tended to be lowest at Station 1 except for hybrids and striped bass (Figure 40). Catch rates along the dam and the riprap bank on the Georgia side of Station 1 were typically very low. Most fish collected at Station 1 came from the rock-rubble habitat along the South Carolina bank.

Seasonal trends in tailrace

Results shown for Station 1 in Figures 37 and 38 illustrate seasonal variation in the total gill netting and electrofishing catches. Trends for the most important species are shown separately for gill netting in Figures 41-43 and electrofishing in Figures 44 and 45. When viewed collectively, the results indicate that several species are abundant year-round, whereas others are seasonally abundant (Table 9). Most of the seasonally abundant species had their highest catch rates in winter or spring.

Table 9

Summary of Seasonal Trends in Abundance of Important Fish Species in the Tailrace of RBR Dam

Species	Information Source
Abundant Year-Round	
Hybrids	Gill netting
Striped bass	Gill netting
Gizzard shad	Gill netting
Largemouth bass	Electrofishing
Bluegill	Electrofishing
Most Abundance in Winter or Spring	
White Bass	Electrofishing
Sauger	Electrofishing
Spotted Sucker	Electrofishing
Silver Redhorse	Electrofishing
Carpsuckers	Electrofishing
Common Carp	Electrofishing
Longnose Gar	Electrofishing

Factors that make more precise definition of seasonality difficult include annual difference in water levels and gear selectivity. Fluctuations in water level may affect access to the tailrace or influence catchability in

nets for some species. The influence of gear selectivity is most obvious for blueback herring, which is known to be abundant in the tailrace, but is not effectively sampled by either the routine gill netting or electrofishing.

Fish abundance near draft tubes

Gill netting conducted on the powerhouse and spillway sides during generation moratoria showed that the abundance of fish (vulnerable to the nets used) was low near the draft tubes (Figure 46). Only 6 species of fish were collected on the powerhouse side, whereas at least 12 were collected near the spillway. Also, catches were much lower on the powerhouse side. For example, the average catch of hybrids was 0.15 kg/net near the powerhouse and 4.4 kg/net along the spillway (Figure 46). The highest catch rates at Station 1 occurred in the routine sets made during periods that included generation cycles.

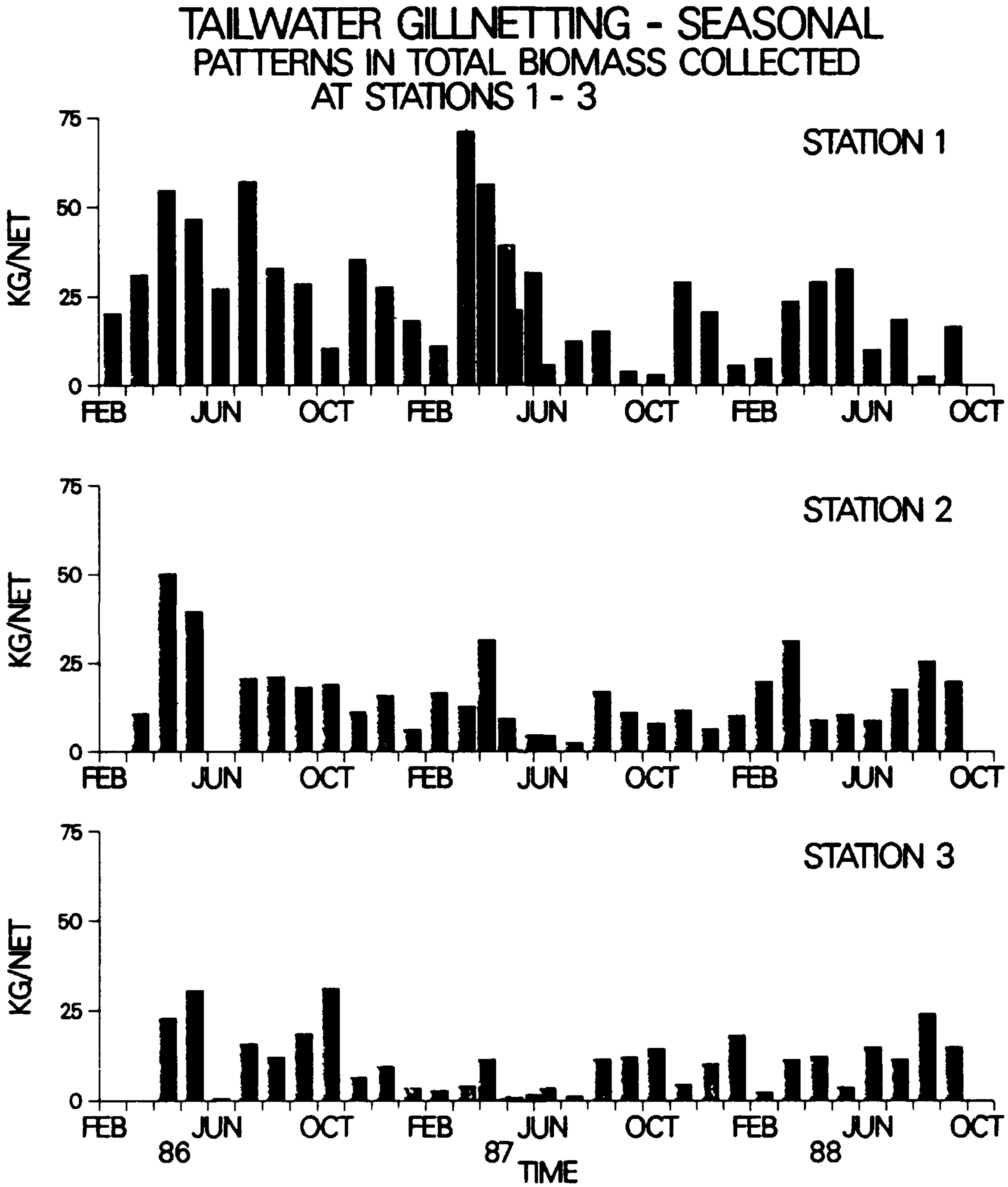

Figure 37. Total fish biomass (species combined) collected in experimental gill nets set at Stations 1-3, February 1988-September 1988

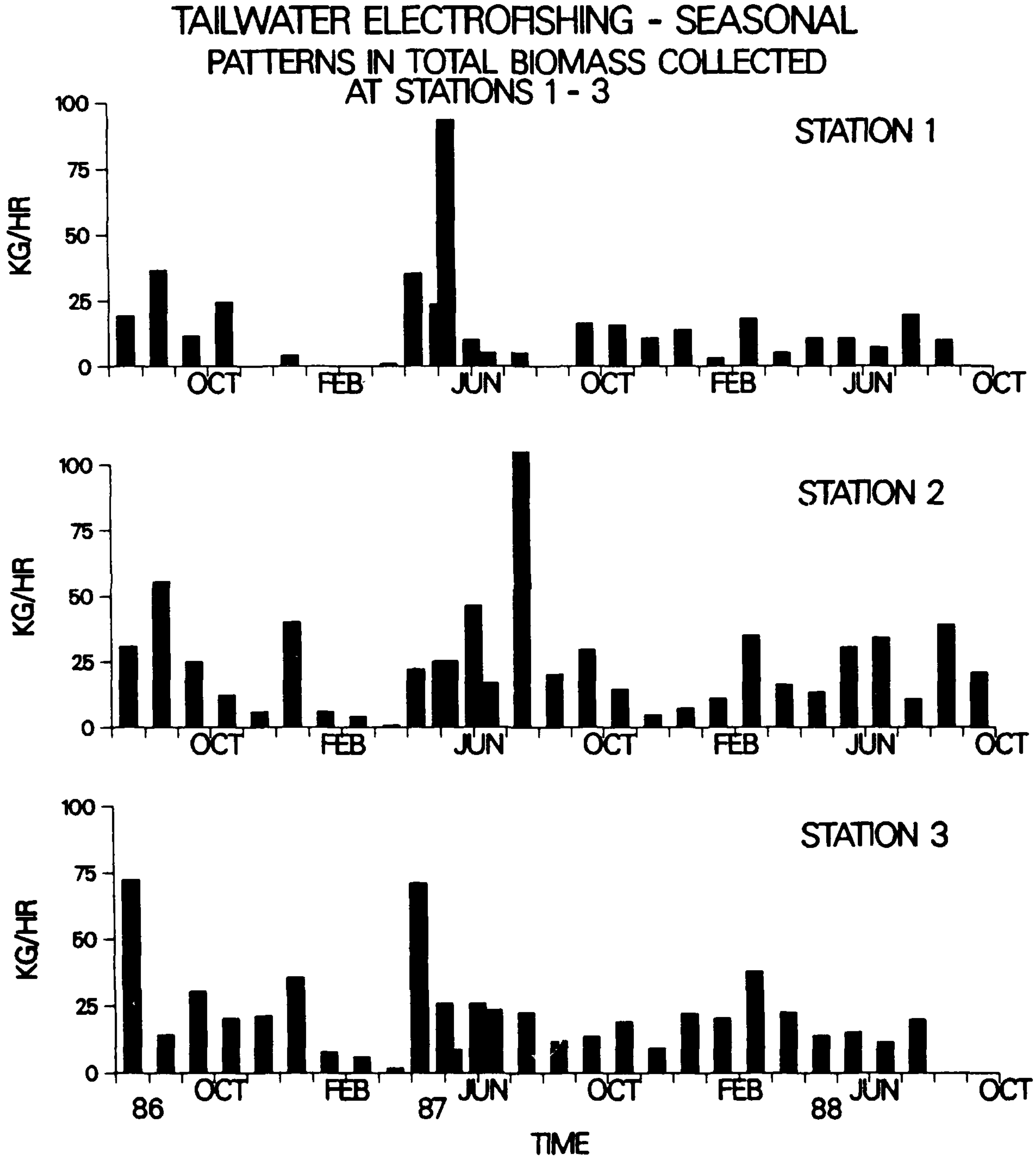

Figure 38. Total fish biomass (species combined) collected by electrofishing at Stations 1-3, July 1986-September 1988

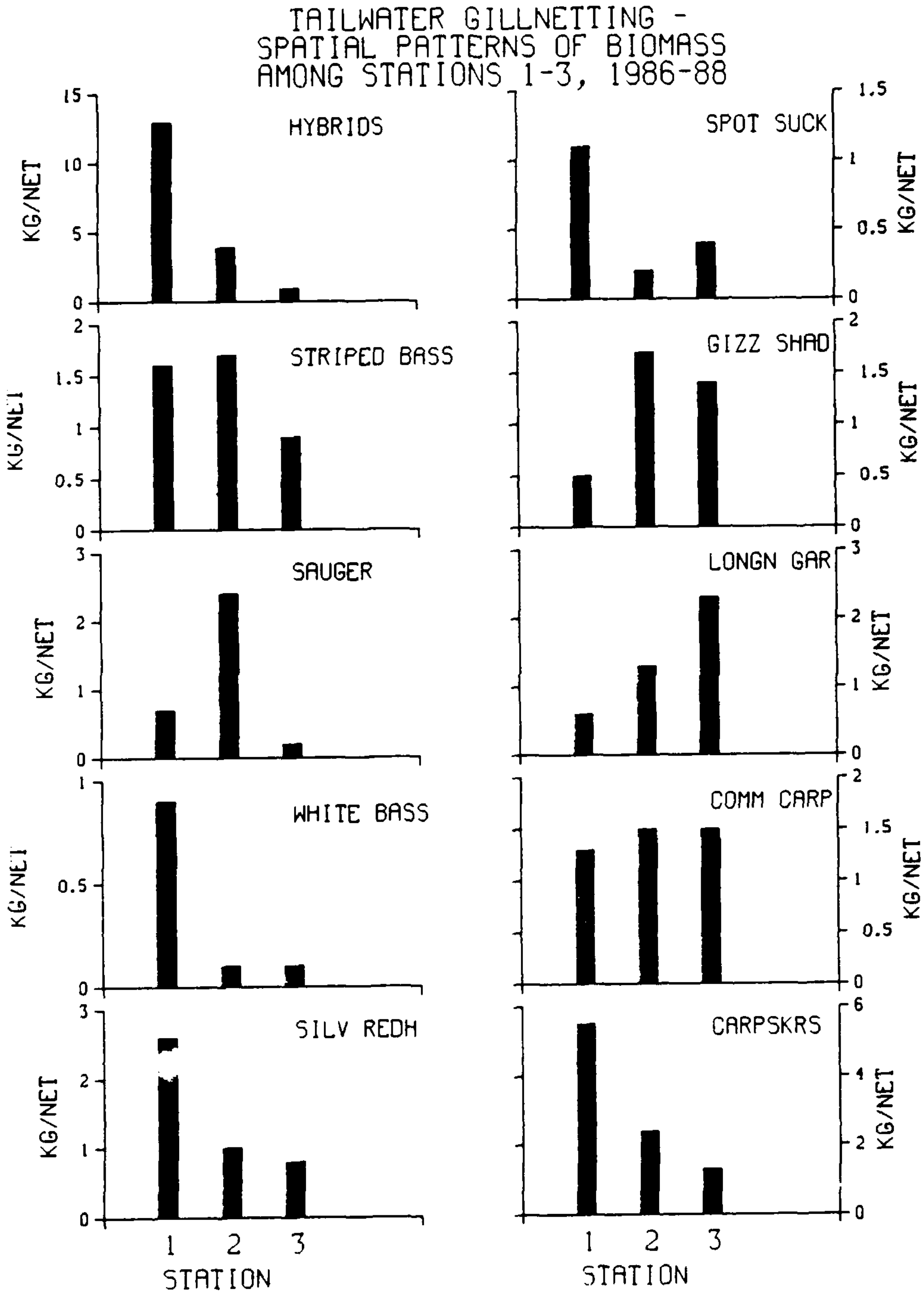

Figure 39. Average biomass in gill nets (across sample periods) pooled for 10 fish species at Stations 1-3, February 1986-September 1988

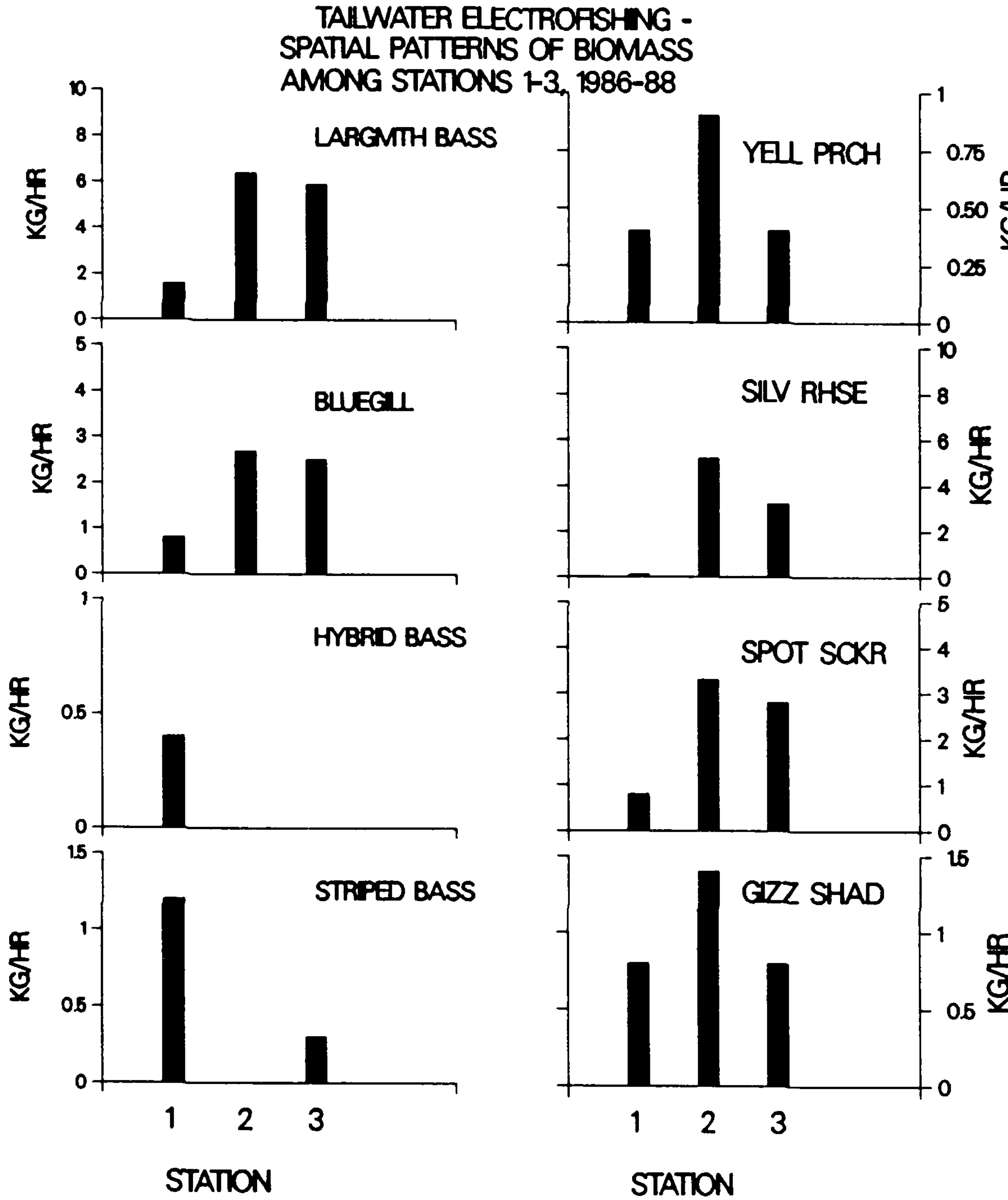

Figure 40. Average electrofishing catch rates (across sample periods) for eight species at Stations 1-3, July 1986-September 1988

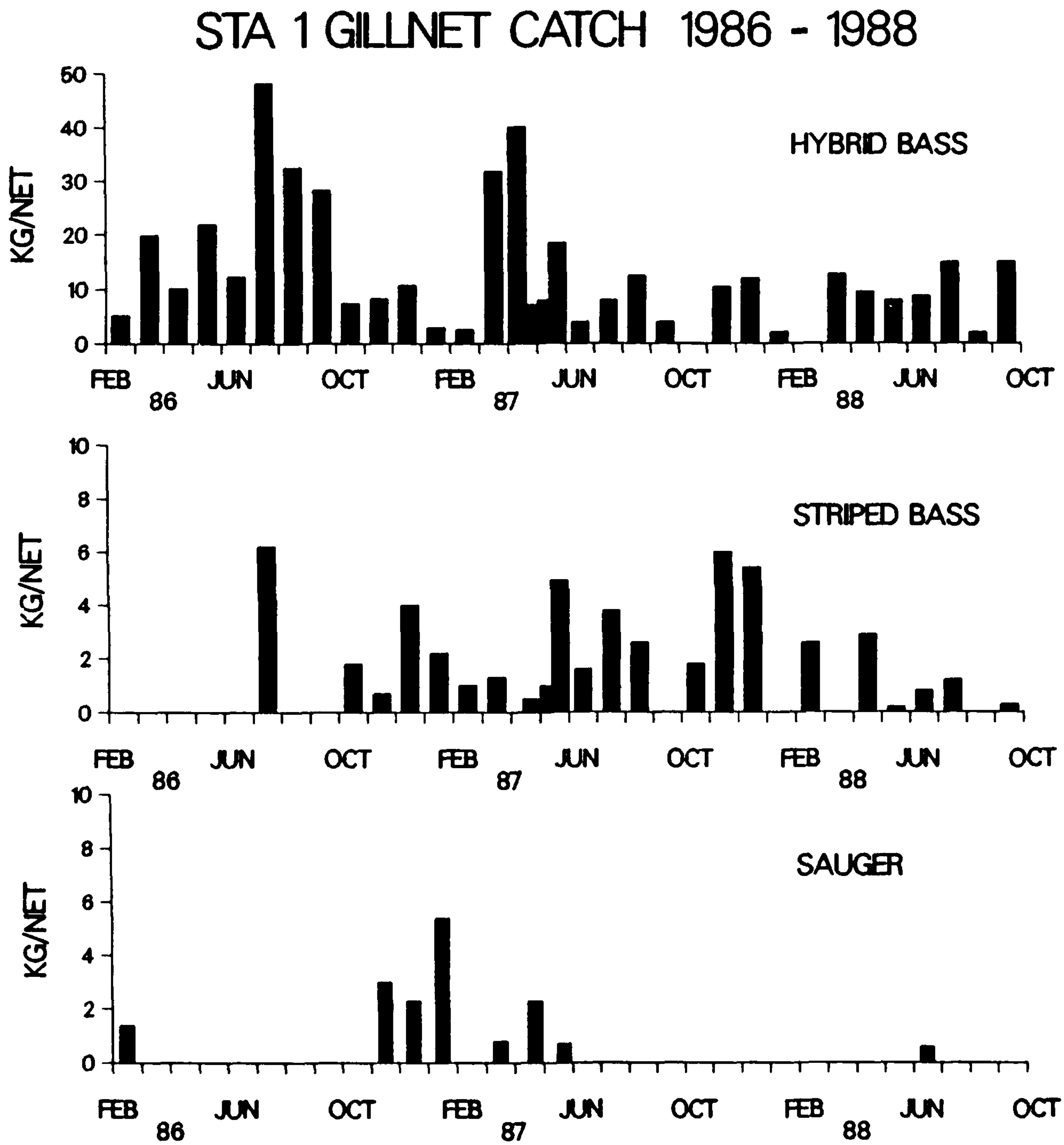

Figure 41. Average catch rates of hybrid bass, striped bass, and sauger in gill nets set at Station 1, 1986-88

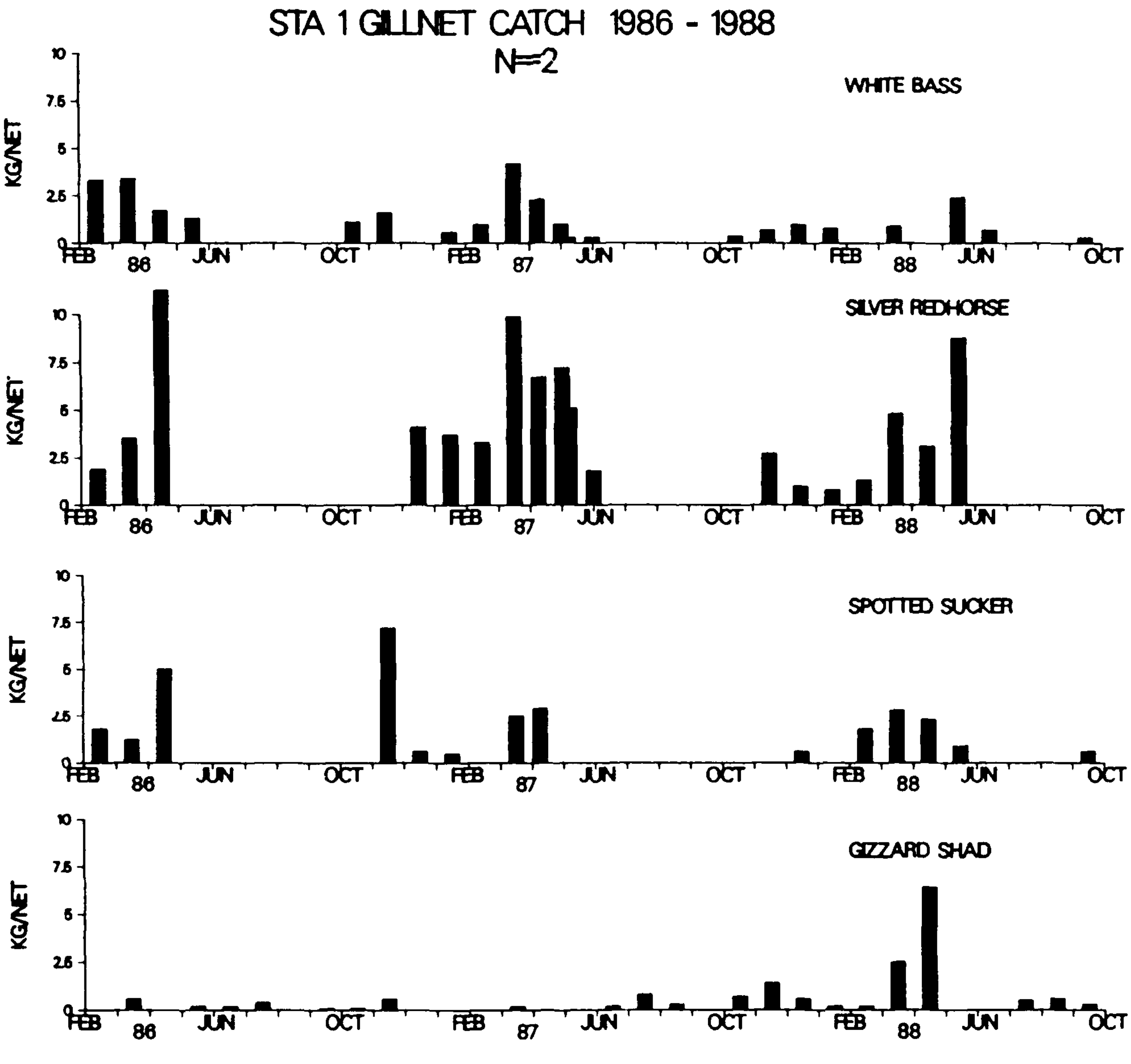

Figure 42. Average catch rates of white bass, silver redhorse, spotted sucker, and gizzard shad in gill nets set at Station 1, 1986-88

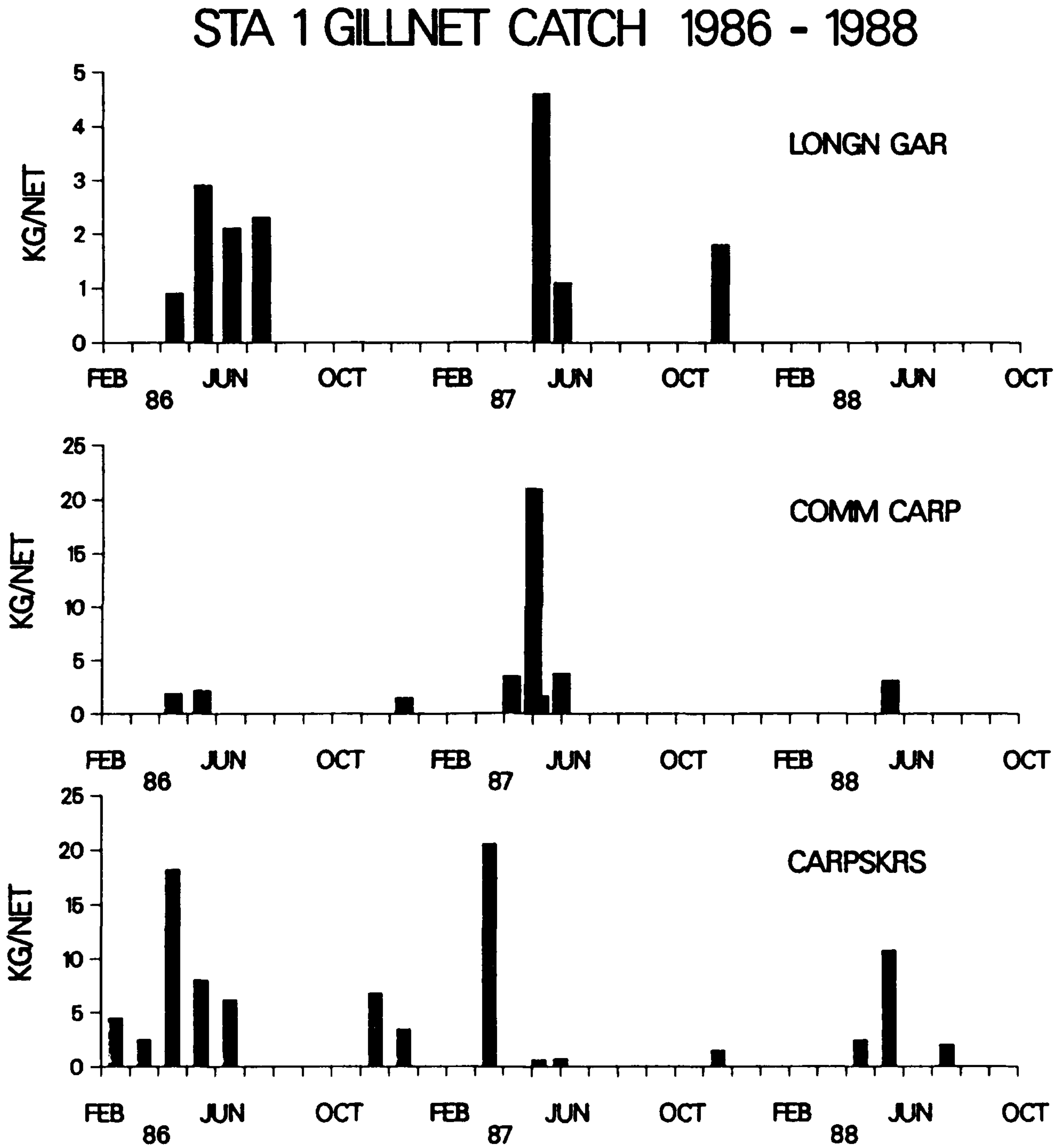

Figure 43. Average catch rates of longnose gar, common carp, and carpsucker in gill nets set at Station 1, 1986-88

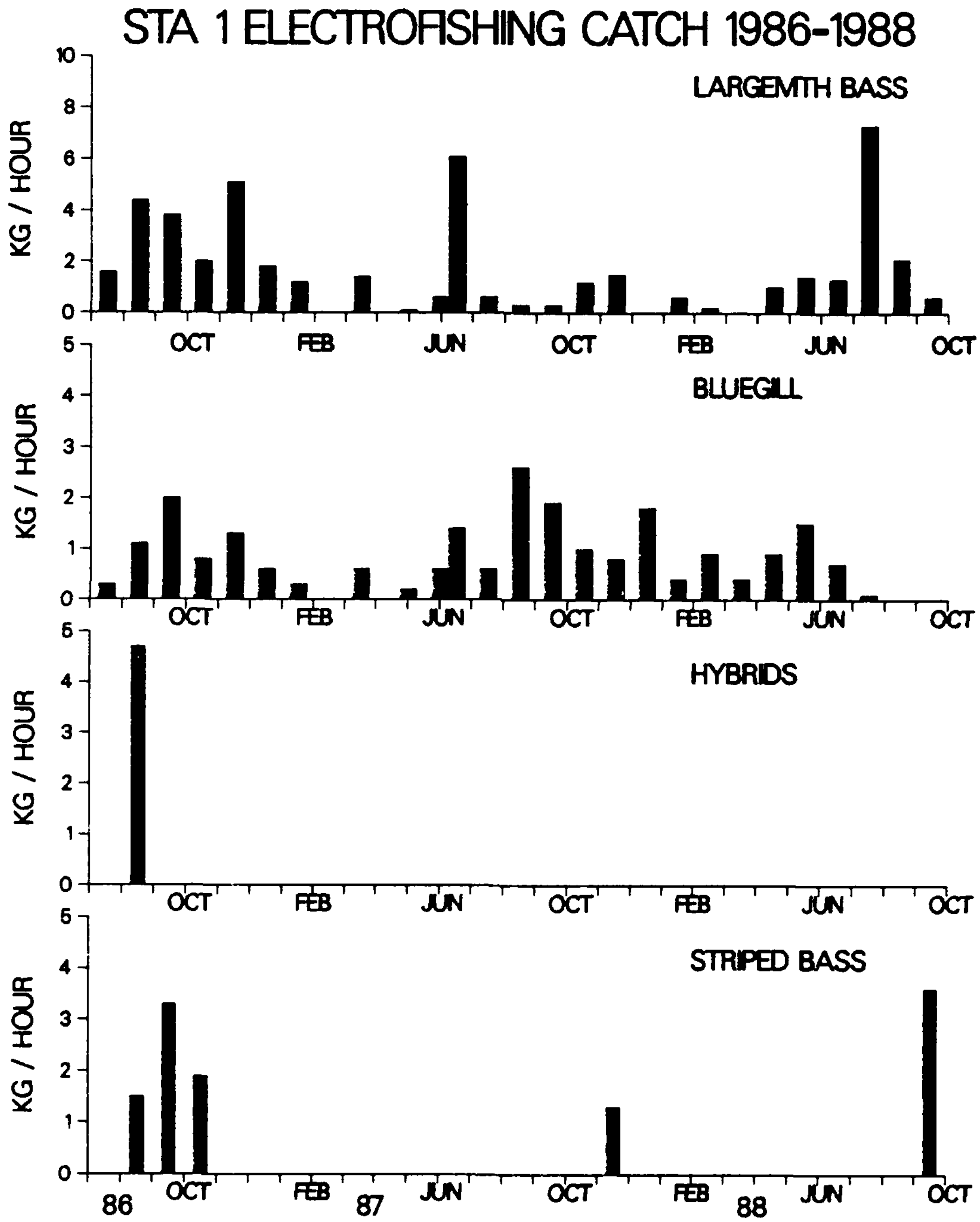

Figure 44. Average electrofishing catch rates for largemouth bass, bluegill, hybrids, and striped bass at Station 1, 1986-88

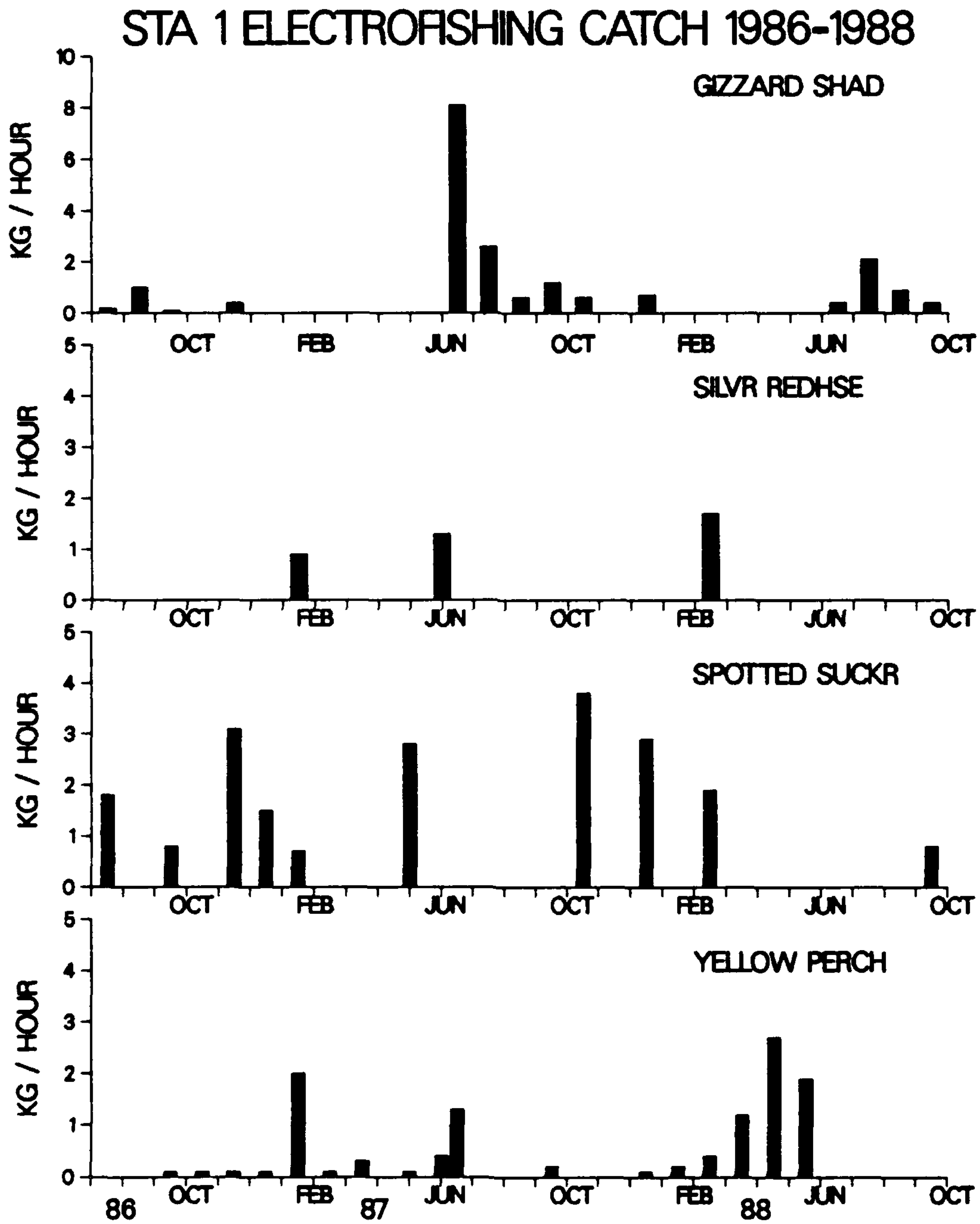

Figure 45. Average electrofishing catch rates for gizzard shad, silver redhorse, spotted sucker, and yellow perch at Station 1, 1986-88

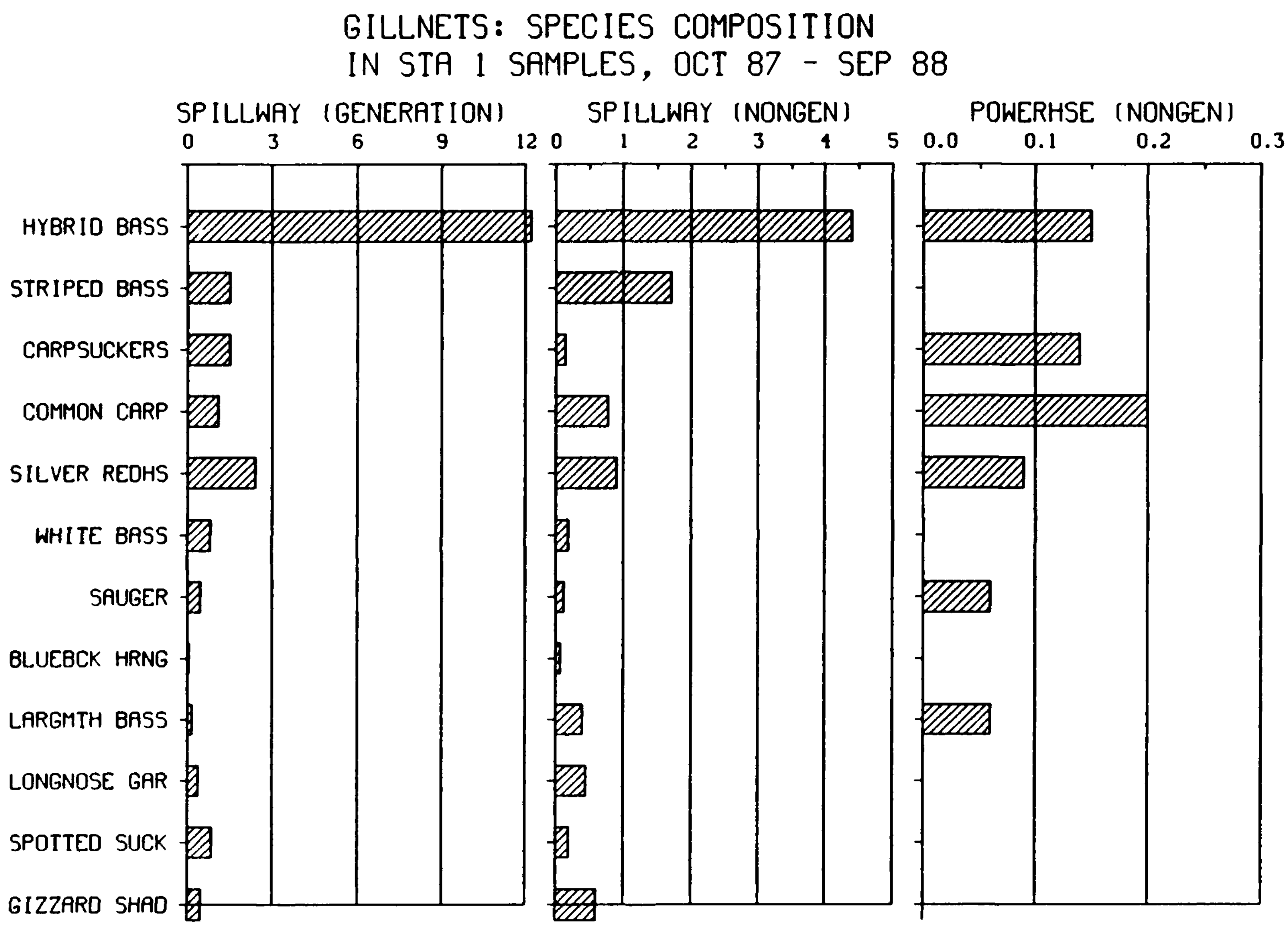

Figure 46. Average catch rates (kg/net) in experimental gill nets set either on the spillway side during generation, along the spillway during nongeneration, or along the powerhouse side of RBR Dam during nongeneration, October 1987-September 1988

NEAR-FIELD HYDROACOUSTICS

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Objectives

Objectives of near-field surveys were to (a) compare fish densities and distributions in the tailrace and tailwater and (b) assess spatial and temporal patterns of fish biomass and fish size as influenced by project operations and other environmental factors.

Methods

Surveys of 11 transects were conducted once or twice monthly during the day to assess the seasonal distribution of fish in RBR tailwater (Figure 47). Surveys were done twice a month in April and May (1986-87) when fish were presumed to be spawning, but only once a month at other times. Effects of day versus night sampling were assessed by comparing daytime surveys to additional surveys conducted at night in July, August, and September 1986 and again in March and June 1988. Tailwater transects were always sampled from west (Georgia side) to east (South Carolina side) and usually began with the transect nearest RBR Dam and proceeded downstream. Transects 13-15 were not sampled during low-water conditions.

Sampling in the tailrace was designed to assess the effects of project operations and seasonal fish distributions. However, complete surveys could not be done during generation because of interference from turbulence. Most sampling was conducted around the generation schedule on preselected days, except for nighttime moratorium surveys in which sampling followed a requested nongenerating period of at least 6 hr.

Four types of tailrace surveys were conducted relative to the time of generation:

a. Postgeneration surveys (RBR Dam after - RDA) were conducted during the day or at night as soon as turbulence dissipated (usually 5 to 10 min).

b. Pregeneration surveys (RBR Dam before - RDB) were conducted after at least 4 hr of no generation during the day.

c. Night surveys (RBR Dam night - RDN) were carried out 1 hr after sunset on a weekend, usually 24 hr after generation ended.

d. Generation surveys usually involved sampling once at night (RBR generation night = RGN) and once during the day (RBR generation day = RGD).

Generation sampling was limited to the spillway area and other low-flow areas (e.g., in front of the proposed pump units). The RDA, RDB, and RDN surveys were conducted once a month, except during April and May, 1986 and 1987, when two surveys per month were thought to be necessary to adequately sample the peak spawning period for many species. The RDA surveys were performed twice each survey period from February 1986 through June 1987; RDB surveys also were replicated but only from February 1986 through June 1986. Monthly RGD and RGN surveys were initiated in July 1987.

Surveys during nongeneration periods (RDA, RDB, and RDN) required 45 to 60 min of stratified sampling of up to 12 parallel transects (Figure 48). Five transects nearest the dam were spaced about 25 m apart to provide detailed data on fish distributions; remaining transects downstream were 50 m apart. Sampling began with the transect nearest the dam and continued with successive transects downstream. Transect sampling always began near the Georgia (west) shore. All 12 transects were surveyed when water-surface elevations permitted (February through July 1986; January through September 1987). Only the first nine transects were regularly sampled at other times.

For comparing tailrace and tailwater biomass, tailrace estimates were computed as the average of echo voltage squared per unit of area sampled at the first nine transects. They were weighted by transect width for each survey type because transect spacing in the tailrace was not uniform. Only the first nine transects were used to provide a consistent comparison because Transects 10-12 were not surveyed during low-water periods. Replicate surveys were averaged to provide one value per period.

Generation surveys (RGD or RGN) involved sampling five to eight transects perpendicular to the dam and from it to the buoy line (Figure 49). Transects were perpendicular to the dam because acoustic interference from turbulence and entrained air prevented sampling in front of or within 50 m of generating units. The number of transects per survey was determined by water level, which limited sampling near the South Carolina side and by the location of generating units on the Georgia side.

In addition to the routine surveys described, diel surveys were conducted at select times to evaluate changes in fish distribution in response to day/night cycles and hydropower releases. Dates and times of hydroacoustic sampling in the tailrace were superimposed on the generation schedule at RBR Dam (Figures 50-52). Diel sampling was conducted in September 1986 and in April, May, and June 1987, and once monthly from April through September 1988. Each diel survey consisted of sampling at 1- to 2-hr intervals for two 24-hr periods. The first 24-hr period started just before or after an RDA survey, and the second began 24 hr after the first one ended and included a generation moratorium period. The first seven transects were sampled every hour during the first 3 to 4 hr and then every 2 hr for the remainder of the 24-hr period. However, all transects sampled during routine surveys were included as part of the diel surveys. In 1986 and 1987, diel surveys were conducted only during nongenerating periods, but in 1988 they were done during generation using transects perpendicular to the dam (Figure 49).

The distribution of fish biomass within transects was obtained in the processing procedure of BioSonics, Inc. Each transect was divided into 10 nearly equal segments laterally and 1-m intervals vertically. Additional resolution was provided by analyzing differences in biomass between adjacent transects.

Results

Elevations

Water-surface elevations in the RBR tailrace were compared with historical elevations of JST Lake at the dam (Figure 53). Average weekly elevations from these separate locations were within ±0.1 ft of one another. From January through September, 1987 was a near normal year, whereas 1986 and 1988 had the lowest recorded elevations in the last 30 years.

Fish biomass

The lowest weighted average biomass at tailwater transects occurred February to May (Figure 54). A weighted average was used because these transects were of highly variable length. Peak biomass occurred in late summer every year. Fall estimates were low in 1986, but high and low values occurred in fall 1987. The November 1987 sample is probably an overestimate for that month as the result of wind-induced turbulence during the sample period. Night samples were 1.3 to 4.2 times higher than the corresponding day samples

based upon five comparisons. Some portion of this difference can be explained by the presence of suspended insect larvae (primarily Chaoborus) in the water column at night. There may also have been less fish avoidance of the boat at night and greater numbers of fish in the water column where they could be acoustically observed. Clupeids often are caught at higher rates in trawls at night than they are during the day because of avoidance (Netsch 1971). The late summer peak in biomass coincided with releases of cool, oxygenated water from RBR Dam, while other portions of JST Lake had warmer water with less oxygen than the tailwater. Fish may prefer the tailwater area in late summer because of lower temperatures and higher oxygen concentrations.

Except for day samples from the tailrace in 1986, peaks in relative fish biomass in the tailrace were at least seven times those in the tailwater (Figure 55). Fish biomass is presented in areal units rather than volume units since water levels varied significantly among surveys. Areal units are more representative of total fish biomass because total area remains nearly constant over a wide range of water levels. Tailwater data are those in Figure 54, but the scale was changed to accommodate tailrace data. Seasonally, biomass in the tailrace was higher from April through September than it was from October through March in all years. Highest nighttime values at the dam were at least 10 times higher than corresponding values in the downstream tailwater during the day or at night.

Although lake levels were higher in spring and summer 1987 than they were in 1986 and 1988, specific reasons for among-year differences in day and night biomass estimates are not clear. Tailrace biomass was lower during the day than at night in low-water years (1986 and 1988) but was higher during the day than at night in 3 of 6 high-biomass months of 1987. Nighttime biomass in spring and summer was lower in 1986 than in 1987 and 1988. Except in May and August, nighttime values in 1988 were similar to 1987 values. Values were much higher in May and lower in August 1988 than in comparable months of 1987 for unknown reasons.

Typical surveys illustrating the vertical and lateral distribution of fish biomass in RBR tailrace indicated that most fish within 50 m of the dam were within 4 m of the surface, although deep water (8 to 16 m) was available in front of the draft tube openings (Figures 56-58). Fish biomass located along transects ≥75 m from the dam was more uniformly distributed vertically in the 4 to 6 m of water column available. No obvious or consistent lateral concentrations of fish were found at any transects. Fish were rarely recorded

deeper than 6 m or in front of the draft tubes (e.g., Figure 57, Transects 1 and 2). Distributions deeper than 6 m may have been caused by boat avoidance, inasmuch as they usually occurred only during the day and involved low relative biomass. On many occasions during daytime sampling, schools of fish within 1 m of the surface were observed moving laterally or down in the water column as the boat approached them. Responses of fish at depths >1 m are unknown. A composite vertical distribution of fish biomass at Transect 1 (immediately below the dam) at night indicated that 90.0 ± 11.2 percent standard deviation (SD) of the fish biomass was within the top third of the water column, and 99.5 ± 1.1 percent SD was above the top of the draft tube openings (Figure 59). The composite was computed by summing average biomass at Transects 1 and 2 by year, season, and depth stratum.

Spatial distribution of fish biomass with respect to distance from the dam was computed by averaging estimates from each transect for the 3 to 4 month period of highest biomass (May-July or May-August) each year (Figures 60-62). In 1986, highest biomass for all survey types was found on Transect 1; lowest values occurred during the day for all transects >100 m below the dam. Close to the dam, night values were lower than postgeneration values, which contained a mixture of day and night surveys following generation periods. A much different pattern was found in 1987. Day values were higher than those obtained either at night or in postgeneration surveys at the first three transects. Peak values for the postgeneration and night surveys in 1987 were located 75 m from the dam at Transect 4 instead of at the dam as in 1986. Peak values in 1988 were located on Transect 1 for the day and night surveys, but biomass was fairly evenly distributed during postgeneration surveys. Night surveys in 1988 (Figure 62) showed secondary peaks 75 and 200 m from the dam (Transects 4 and 7) that were much higher than a similar peak in 1986 (Figure 60, Transect 7). Low biomass in postgeneration surveys in 1988 probably resulted from more sampling during daylight hours because of reduced generation during drought. During 1986 and 1987, postgeneration surveys were sometimes conducted during the day and sometimes at night depending on the generation schedule for a particular survey. The spatial distribution of fish biomass in the tailrace (Transects 1-12) and tailwater (Transects 13-23) can also be viewed on an areal basis by pooling data from all depth strata by transect segment. Representative examples of day and night distributions are shown in Figures 63 and 64, respectively. In February 1987, biomass in the tailrace was lower and more widely dispersed during the

day (Figure 63) than at night (Figure 64). In May 1987, more biomass was concentrated in the tailrace than in the tailwater, and this trend was more pronounced during the day (Figure 63) than at night (Figure 64). In August 1987, biomass was not as concentrated close to the dam as it was in May, and concentrations in the tailwater were higher than those observed in May or February. Also, more fish biomass was present in the tailrace at night than during the day. By November and December, the distribution of biomass in the tailrace was similar to that in the tailwater (cf. fourth quadrants, Figures 63 and 64). Diel patterns of fish distribution based upon averages from Transects 1-5 at the dam for 10 different monthly periods (1986-88) are shown in Figures 65-74. Biomass scales vary among figures to show the most detail possible. Variance in biomass among the first five transects probably would be higher than that associated with five replicate samples from one transect. If fish were uniformly distributed within the first five transects, biomass per unit area would be greater close to the dam because a greater volume of water was sampled there than at successive transects downstream. Fish biomass may have been higher near the dam because many species of fish are attracted to areas that are shaded and contain structure. The RBR dam provided both attractions.

In 8 of 10 diel survey periods, fish biomass appeared to be greater at night than during the day. Whether this result was an artifact of sampling bias (perhaps due to boat avoidance) or reflected true differences in distributions is unclear. In 4 of 10 diel surveys, biomass was greater during the nighttime moratorium period than during the previous nighttime (or postgeneration) period (Figures 65, 68, 70, and 72). Only two surveys showed an apparently significant difference between successive nighttime periods (Figures 65 and 69). Two surveys recorded higher during the first nighttime (or postgeneration survey) period than during the second nighttime moratorium period (Figures 69 and 71). None of the diel surveys showed any apparent differences between postgeneration, generation, or moratorium periods during the day.

Diel surveys conducted with and without artificial illumination indicated that lights in the vicinity of the dam had minimal effect on the distributions of fish biomass in the tailrace. Normally lights along the face of the dam, in the powerhouse, and on the fishing pier were left on during acoustic surveys, although frequently some portion of these may have been turned off or burned out. The unlighted postgeneration survey was the same in

all respects as one conducted the next night with lights illuminating the area. Results of the lit and unlit surveys were compared with another moratorium survey, also conducted at night with lights (Figure 68). Although minor changes in distribution may have occurred, echograms and cross-section plots of fish biomass distributions did not reveal any gross differences between lit and unlit surveys. However, high fish biomass was observed on a few occasions in the immediate vicinity of underwater lights used by fishermen to attract bait fish (along Transects 8-12 in summer 1987).

Relative size

Except in 1988, the highest average target strengths (relative size) of fish in the tailwater were significantly higher than those of fish in the tailrace. Target strength distributions for night moratorium surveys in the tailrace in 1986, 1987, and 1988 (Figures 75-77) were compared with those from the tailwater in comparable years (Figures 78-80). The relation between target strength and fish length was given in Figure 47. Mean relative lengths of fish in night moratorium surveys below RBR Dam ranged from 6.1 to 10.4 cm in 1986, from 4.3 to 15.0 cm in 1987, and from 11.9 to 19.3 cm in 1988 (Figures 75-77). Distributions with fewer than 50 targets were not plotted. Monthly mean lengths in the tailwater ranged from 6.9 to 37.3 cm in 1986, from 3.8 to 59.7 cm in 1987, and from 9.1 to 44.5 cm in 1988 (Figures 78-80). Greatest numbers of targets in the tailrace were found from April or May through September every year, corresponding closely with those months when biomass was highest.

Nearly all targets were within 4 m of the surface, although there were more targets in the 4- to 6-m range in 1987 than in 1986. Mean depths of targets in the tailrace ranged from 1.7 to 2.5 m in 1986, from 1.9 to 3.1 m in 1987, and from 1.9 to 2.5 m in 1988. Mean depths probably are somewhat shallower than these depths indicate because the first metre below the surface was excluded from sampling due to electronic distortions near the transducer.

The tailrace was sampled with a 91.4- by 9.1-m purse seine during moratorium acoustic sampling from March through September 1988 to provide species composition data and to corroborate target strength estimates of relative length. Target strength and biomass data indicated that most fish near the dam were small and surface-oriented; direct observations suggested that most were blueback herring. However, gill netting and electrofishing did not collect this species in proportion to its apparent abundance. The purse seine was set over areas of high fish density as identified with acoustics. A

subsample of 300 to 400 fish from different portions of the net was used to estimate species composition.

Purse-seining data from March through July indicated that at least 93 percent of the small fish in open surface waters near the dam were blueback herring (Table 10). Samples in May, June, and July contained only blueback herring. Other species collected in March and April included gizzard shad, threadfin shad, and spottail shiners. August and September samples were omitted because only three fish were sampled in August, and the September sample was plagued by logistical problems.

Table 10

Percent Composition of Purse Seine Catches from RBR Tailrace from March Through July 1988

Species	March	April	May	June	July
Blueback herring	93.3	98.4	100.0	100.0	100.0
Gizzard shad	1.8	1.0	--	--	--
Threadfin shad	4.9	--	--	--	--
Spottail shiner	--	--	--	--	--

Average lengths of fish estimated by hydroacoustics were significantly lower than those of fish in purse-seine samples ($P < 0.0001$). Average lengths of fish in the purse seine ranged from 14.6 cm in June to 16.3 cm in April, whereas acoustically estimated means ranged from 6.9 in June to 10.9 in September. The relation used to estimate fish lengths from target strength data (Love 1977) apparently is not appropriate for blueback herring below RBR, as lengths are consistently underestimated. The equation of Love (1977) was based upon target strength and length data from several species of fish over a wide range in lengths (0.34 to 34.4 cm). Also, target strength is an accurate reflection of fish length only when fish are oriented at a right angle to the acoustic beam and underestimates length when fish are oriented otherwise.

Summary

Acoustic surveys revealed relatively high biomass near the dam from April to September, and the highest biomass was usually within 100 m of the dam. Relatively low biomass was located near the dam from October through March, and over 90 percent was in the upper third of the water column above the level of the draft tubes. Biomass near the dam consisted predominantly of small blueback herring. Diel surveys showed no predictable patterns of fish distribution relative to project operations. Relative fish biomass was much higher in the tailrace than in the downstream tailwater, particularly during spring and summer. Peak biomass in the downstream tailwater occurred in late summer.

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Netsch, N. F. 1971. "Distribution of Young Gizzard and Threadfin Shad in Beaver Reservoir," pp 95-105 in G. E. Hall, ed., Reservoir Fisheries and Limnology, American Fisheries Society Special Publication, No. 8.

Love, R. H. 1977. "Target Strength of an Individual Fish at Any Aspect," Journal of the Acoustical Society of America, Vol 62, pp 1397-1403.

RBR HYDROACOUSTIC SURVEYS

TAILWATER TRANSECTS

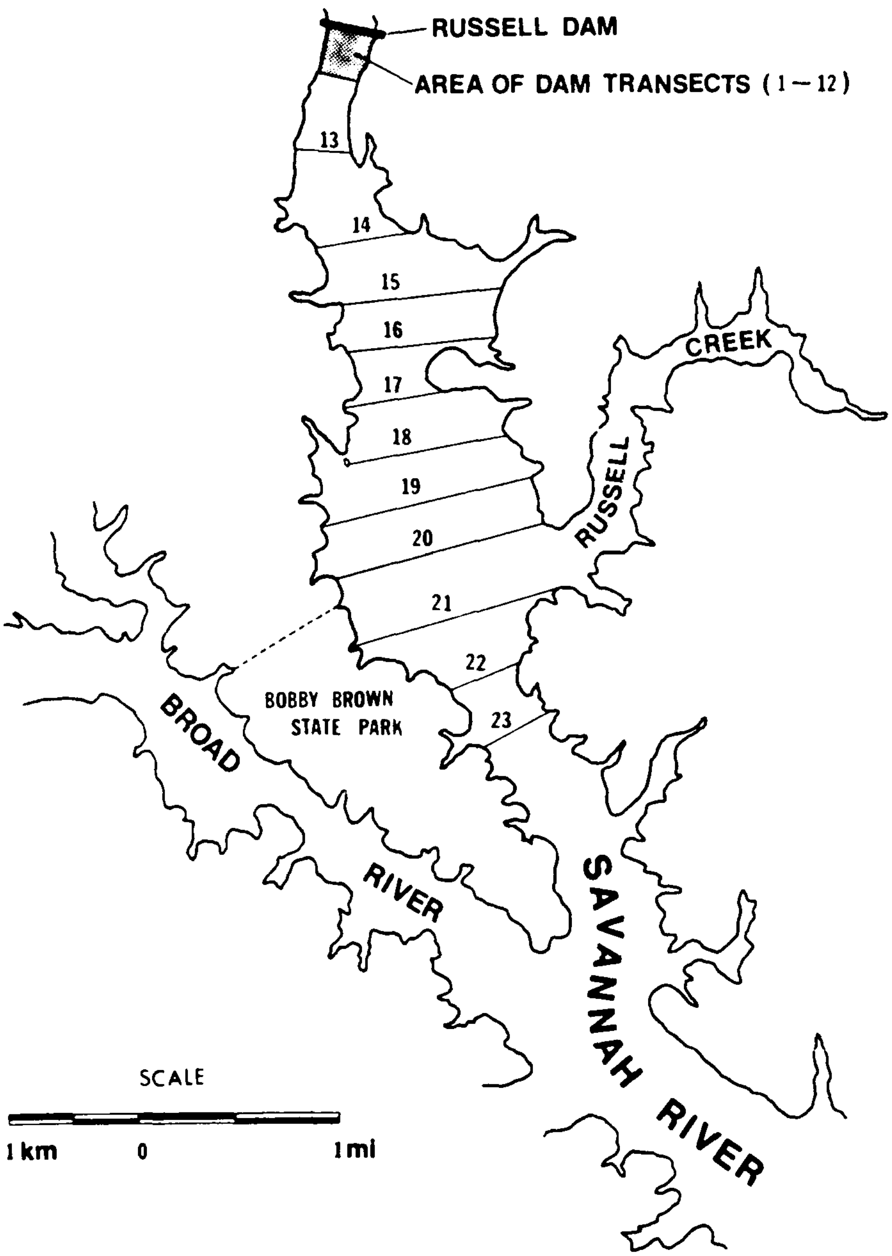

Figure 47. Savannah River and Broad River arms of JST Lake below RBR Dam, showing the location of tailwater hydroacoustic transects

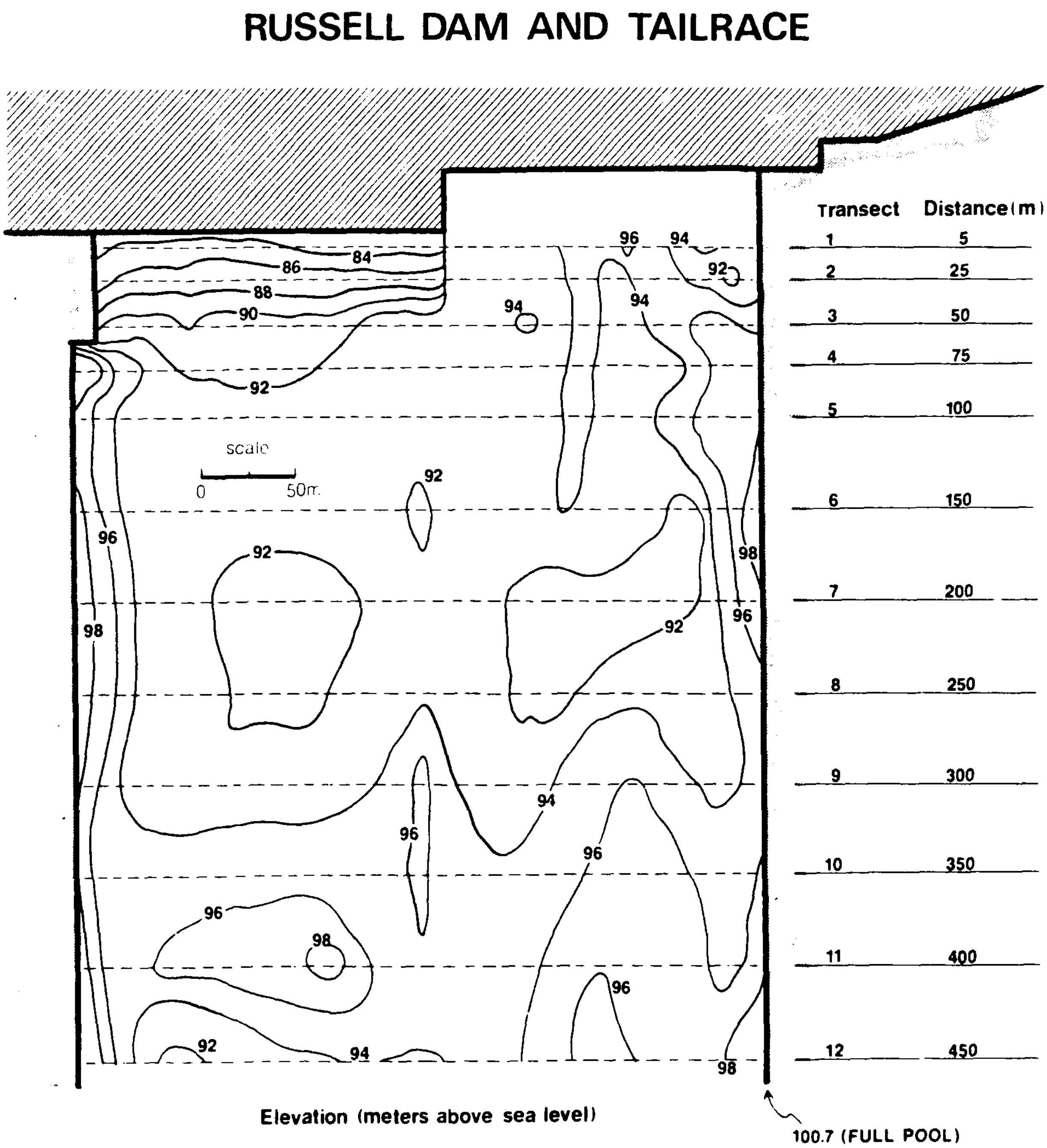

Figure 48. Bathymetric map of RBR Dam tailrace showing the location of hydroacoustic transects surveyed during nongeneration periods

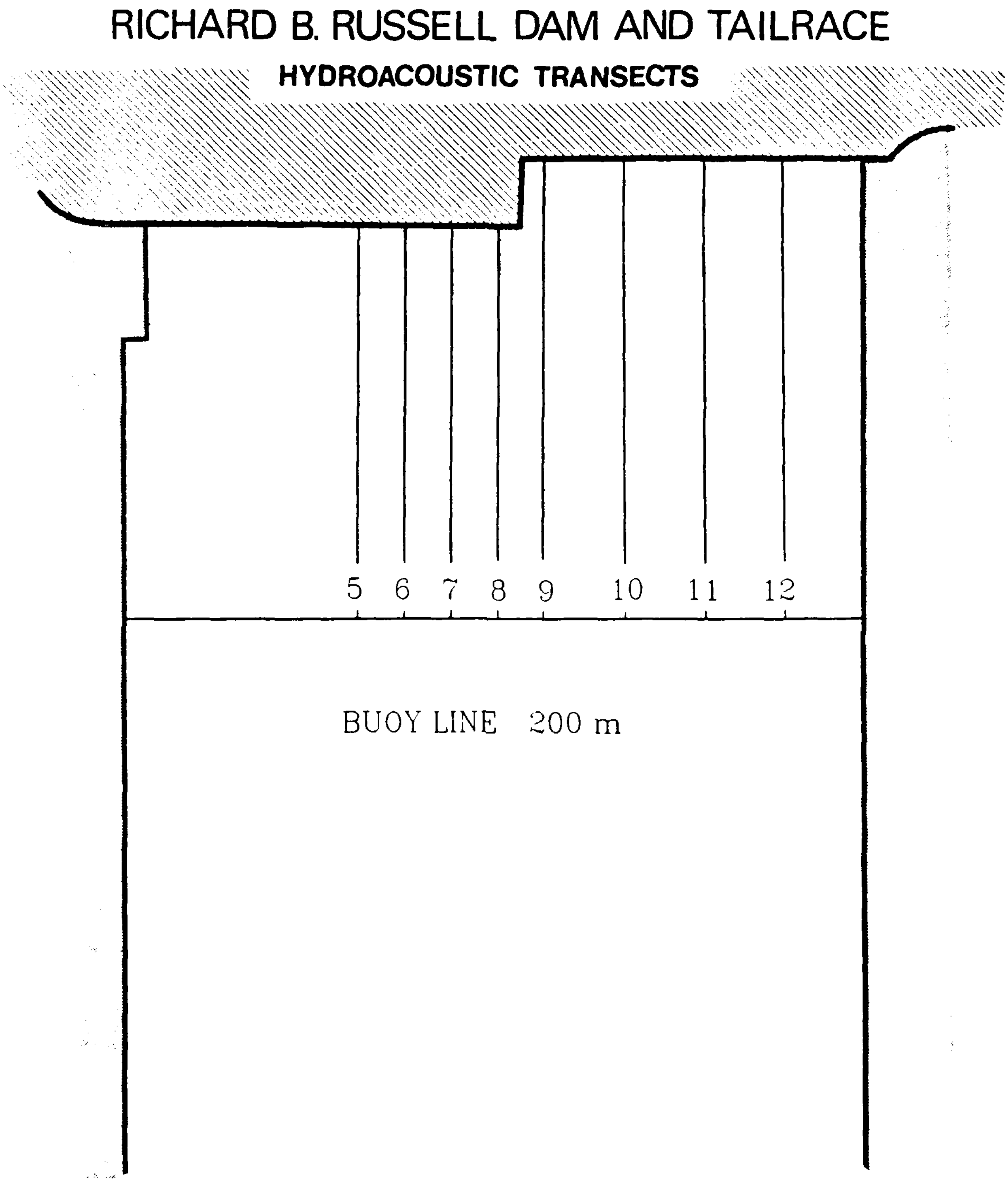

Figure 49. Diagram of RBR Dam and tailrace showing location of hydroacoustic transects surveyed during generation periods

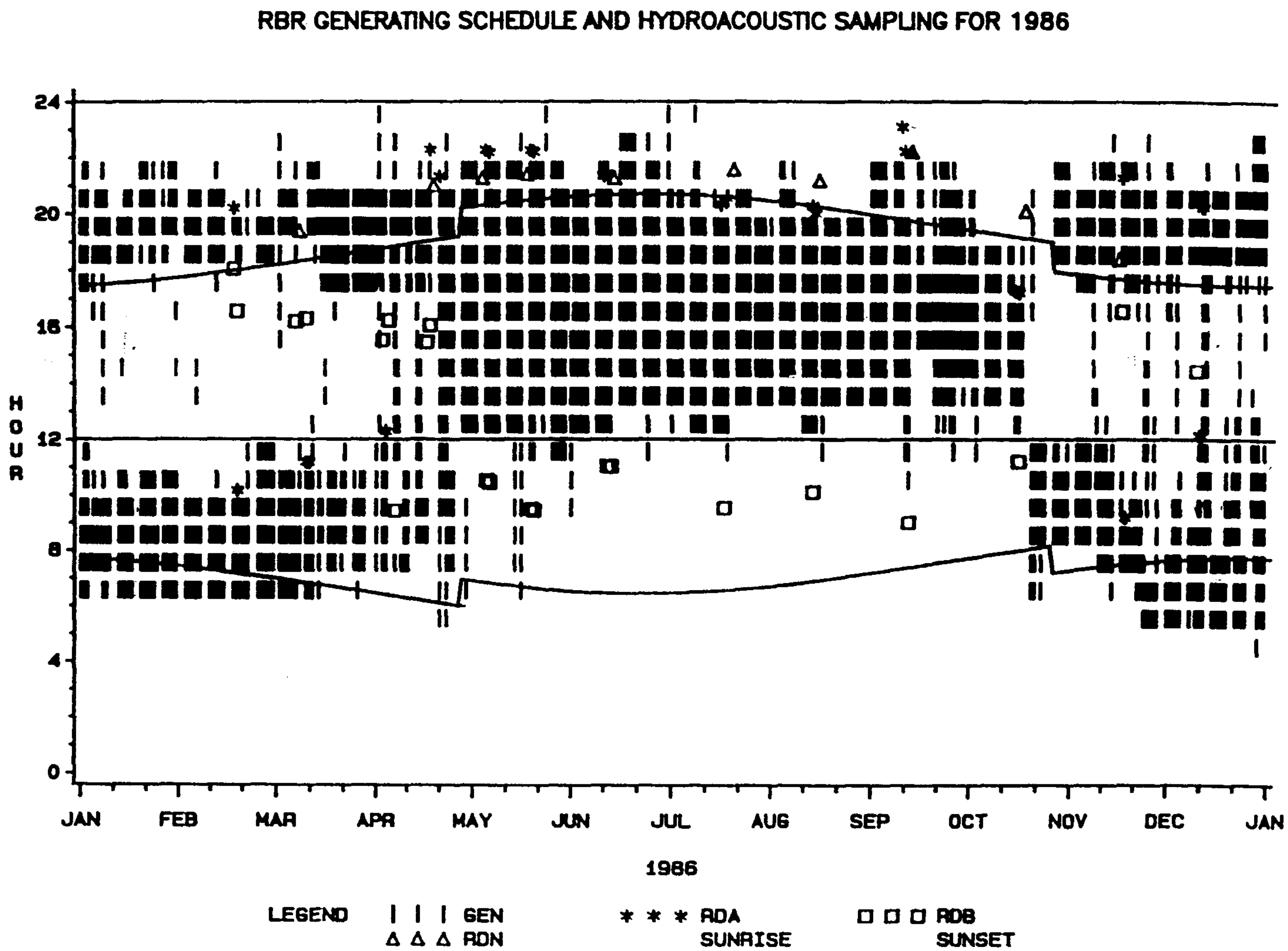

Figure 50. Schedules of hydroacoustic sampling and RBR Dam operations in 1986. Hours of generation are indicated by black vertical lines, routine surveys by open symbols, and diel surveys by darkened symbols. Local time of sunrise and sunset is indicated by solid lines through days

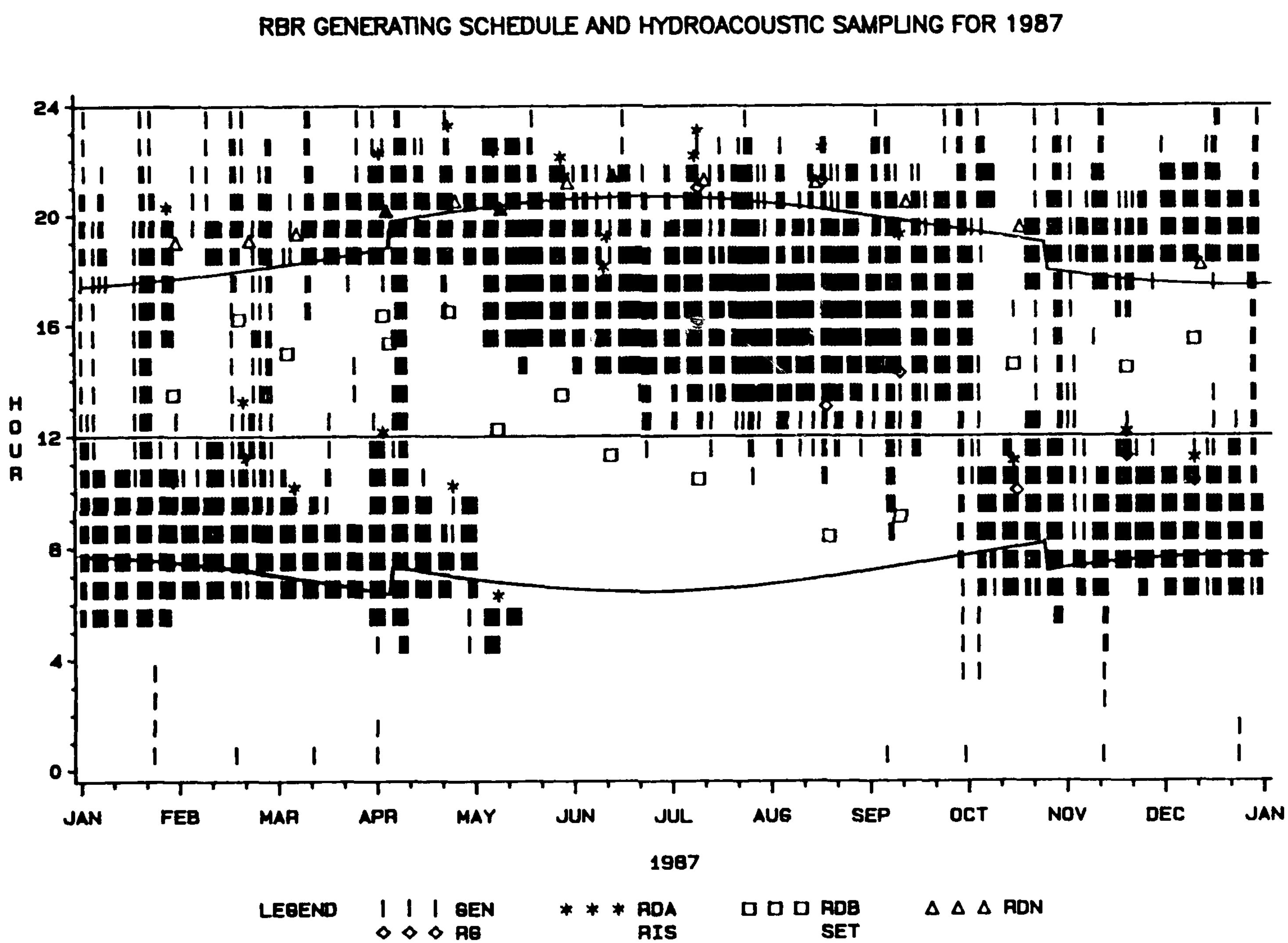

Figure 51. Schedules of hydroacoustic sampling and RBR Dam operations in 1987. Hours of generation are indicated by black vertical lines, routine surveys by open symbols, and diel surveys by darkened symbols. Local time of sunrise and sunset is indicated by solid lines through days

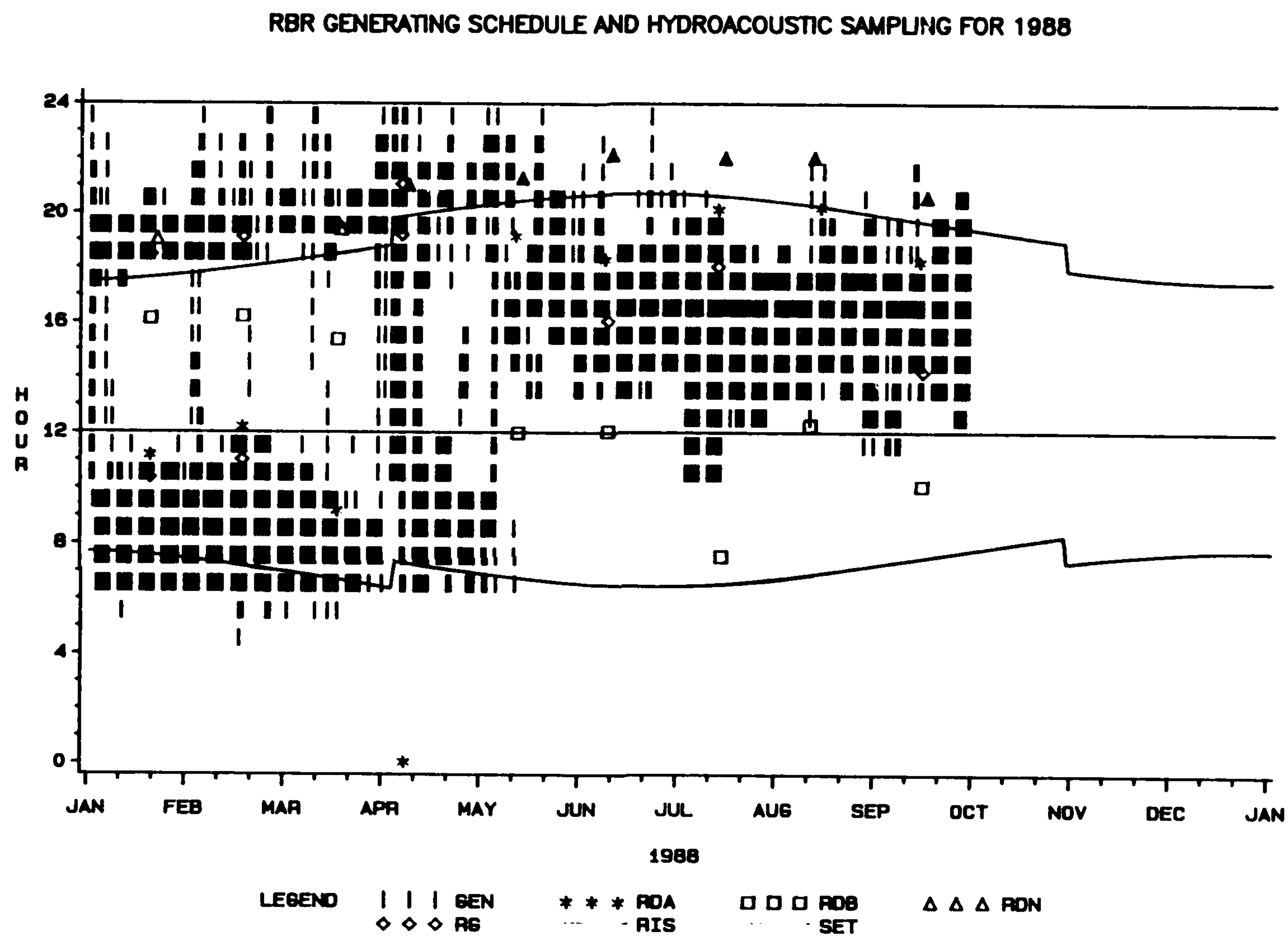

Figure 52. Schedules of hydroacoustic sampling and RBR Dam operations in 1988. Hours of generation are indicated by black vertical lines, routine surveys by open symbols, and diel surveys by darkened symbols. Local time of sunrise and sunset is indicated by solid lines through days

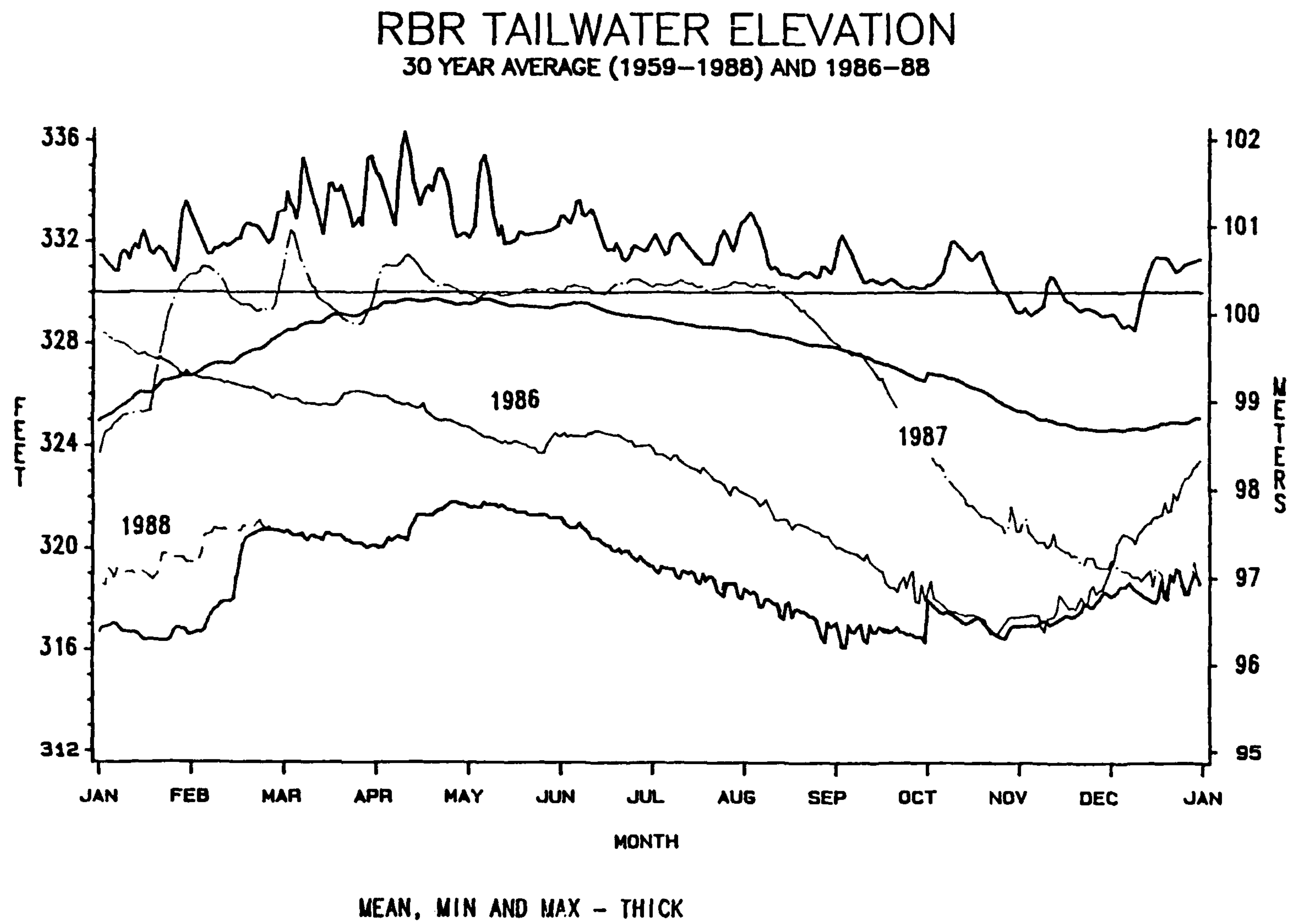

Figure 53. J. Strom Thurmond Lake elevation from January 1986 to September 1988 compared with the 30-year average and historical daily minimum and maximum elevations for the last 30 years (1959-1988)

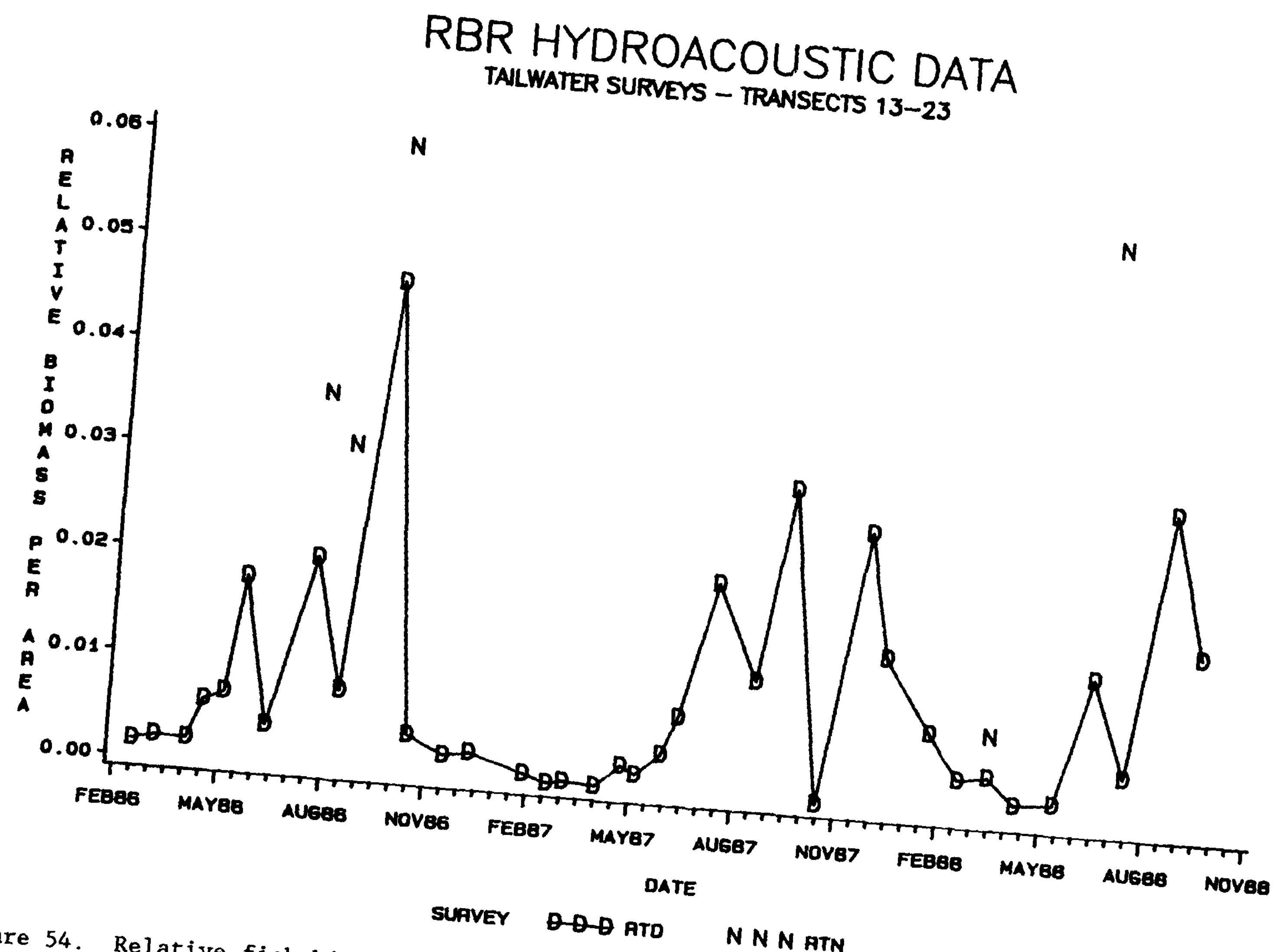

Figure 54. Relative fish biomass in RBR tailwater during the day (RTD) and at night (RTN) from February 1986 to September 1988. Values represent the mean of tailwater transect values weighted by transect length

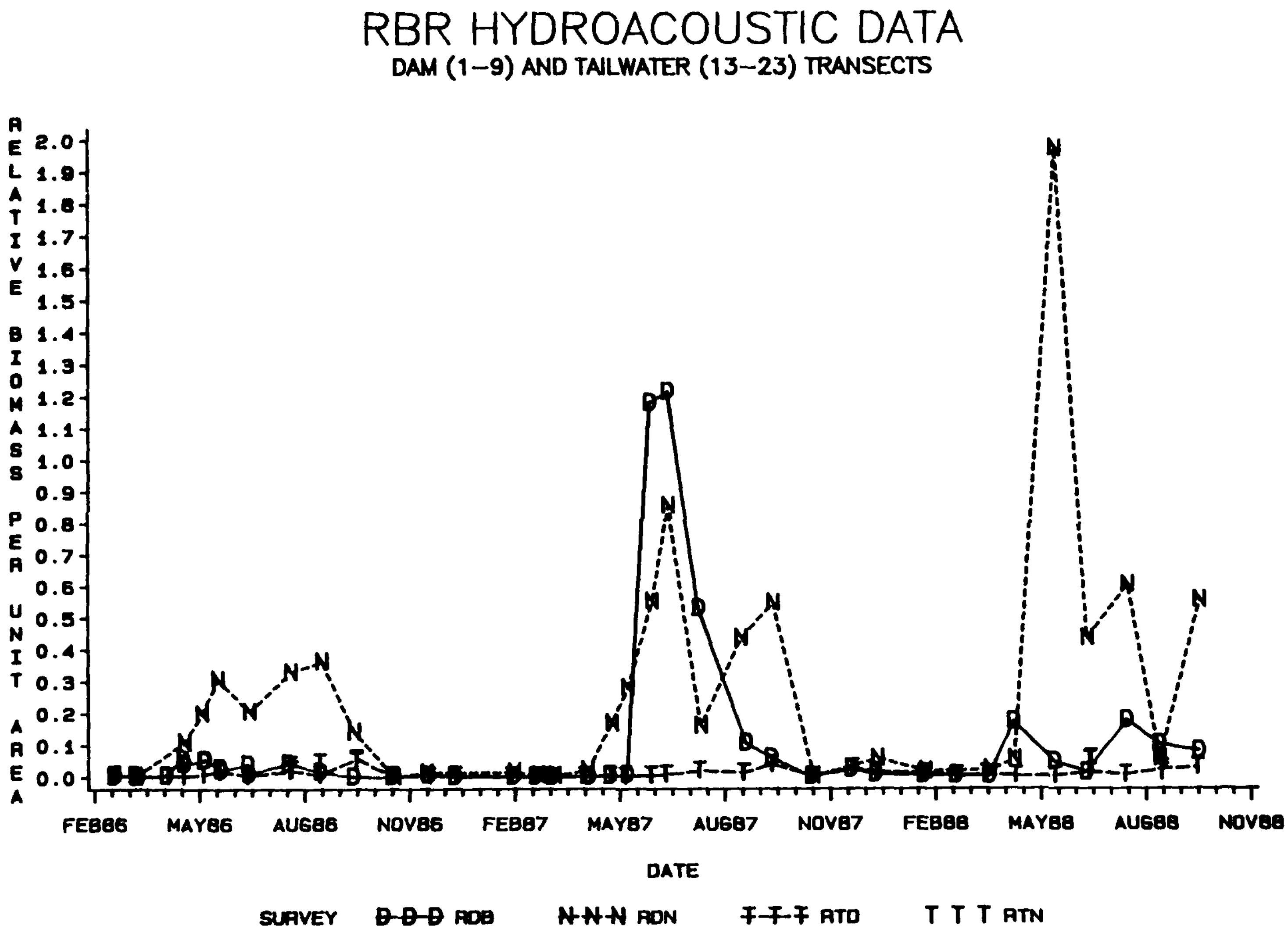

Figure 55. Relative fish biomass in RBR tailwater during the day (RTD) and at night (RTN) as compared with the RBR Dam tailrace surveys pregeneration daytime periods (RDB) and nongeneration periods at night (RDN). Means of Transects 1-9 (weighted by transect width) in the tailrace are compared with means of Transects 13-23 (weighted by transect lengths) in the tailwater

The top of 1 m of the water column was not sampled due to electronic distortions near the transducer. WSEL = water surface elevation

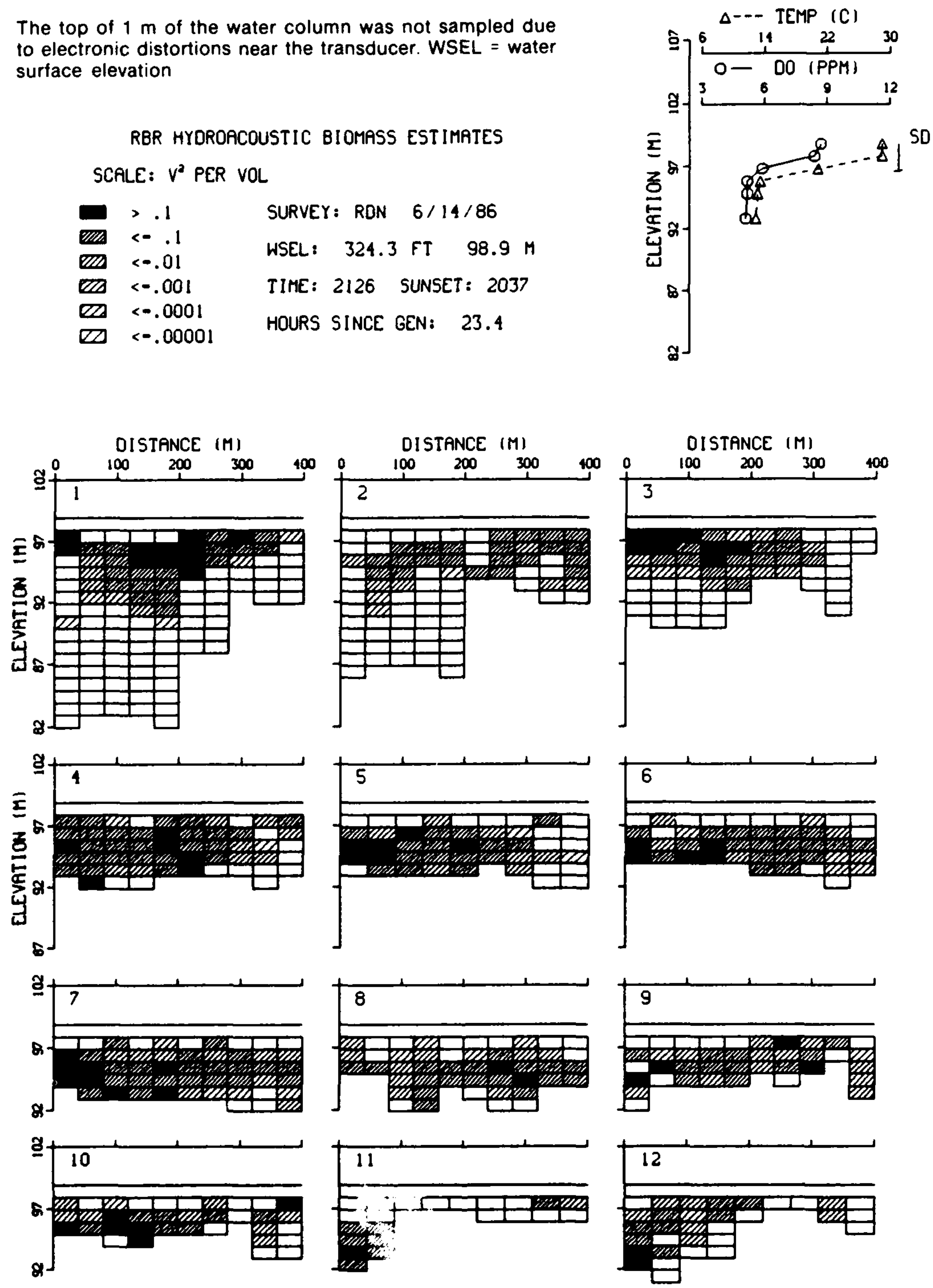

Figure 56. Vertical and lateral distribution of relative fish biomass during the night moratorium survey (RDN) conducted on 14 June 1986. Temperature and dissolved oxygen profiles are presented along with other information. Different shadings represent order of magnitude differences in fish biomass

The top of 1 m of the water column was not sampled due to electronic distortions near the transducer. WSEL = water surface elevation

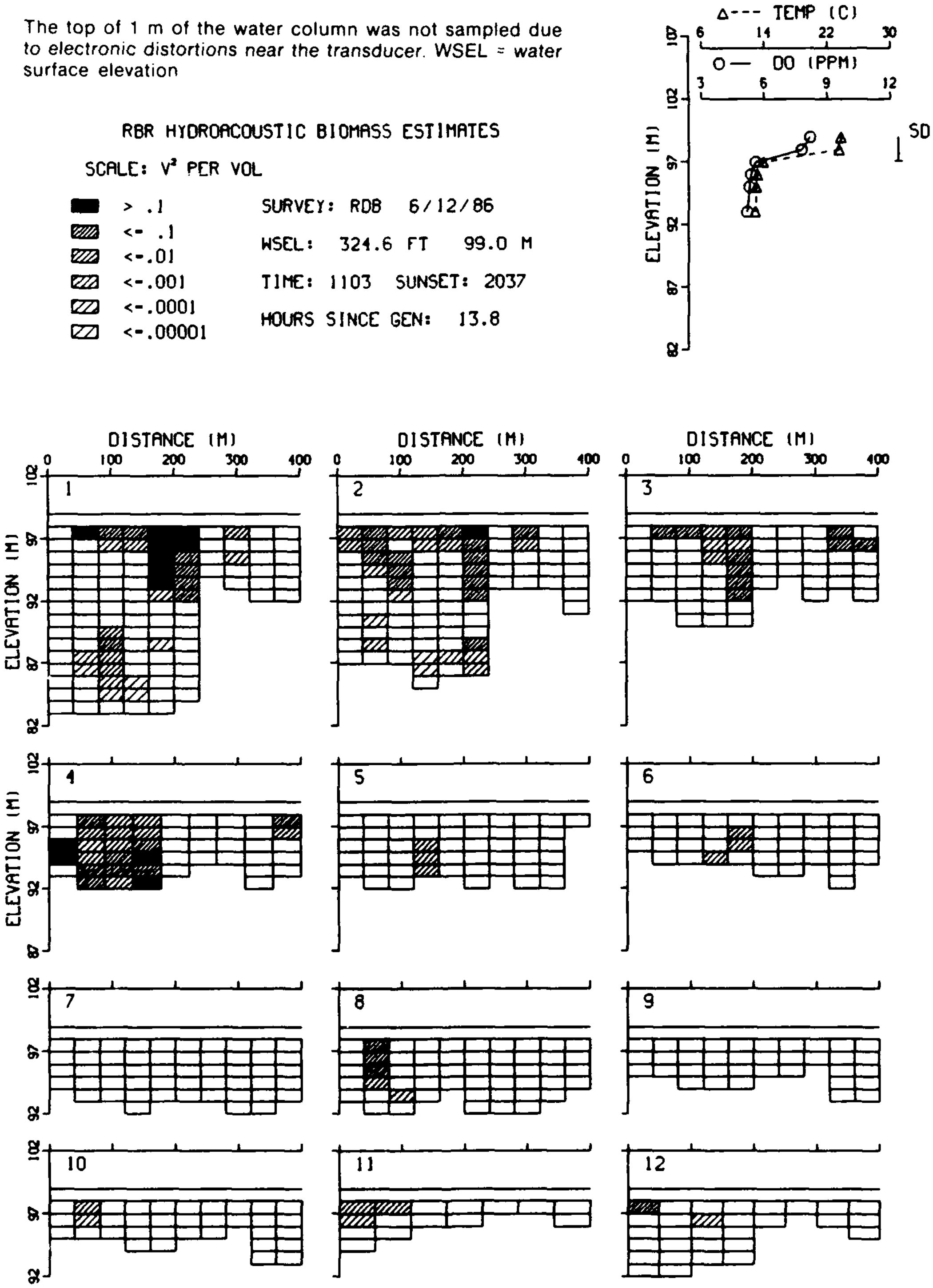

Figure 57. Vertical and lateral distribution of relative fish biomass during the pregeneration survey (RDB) conducted on 12 June 1986. Temperature and dissolved oxygen profiles are presented along with other information. Different shadings represent order of magnitude differences in fish biomass

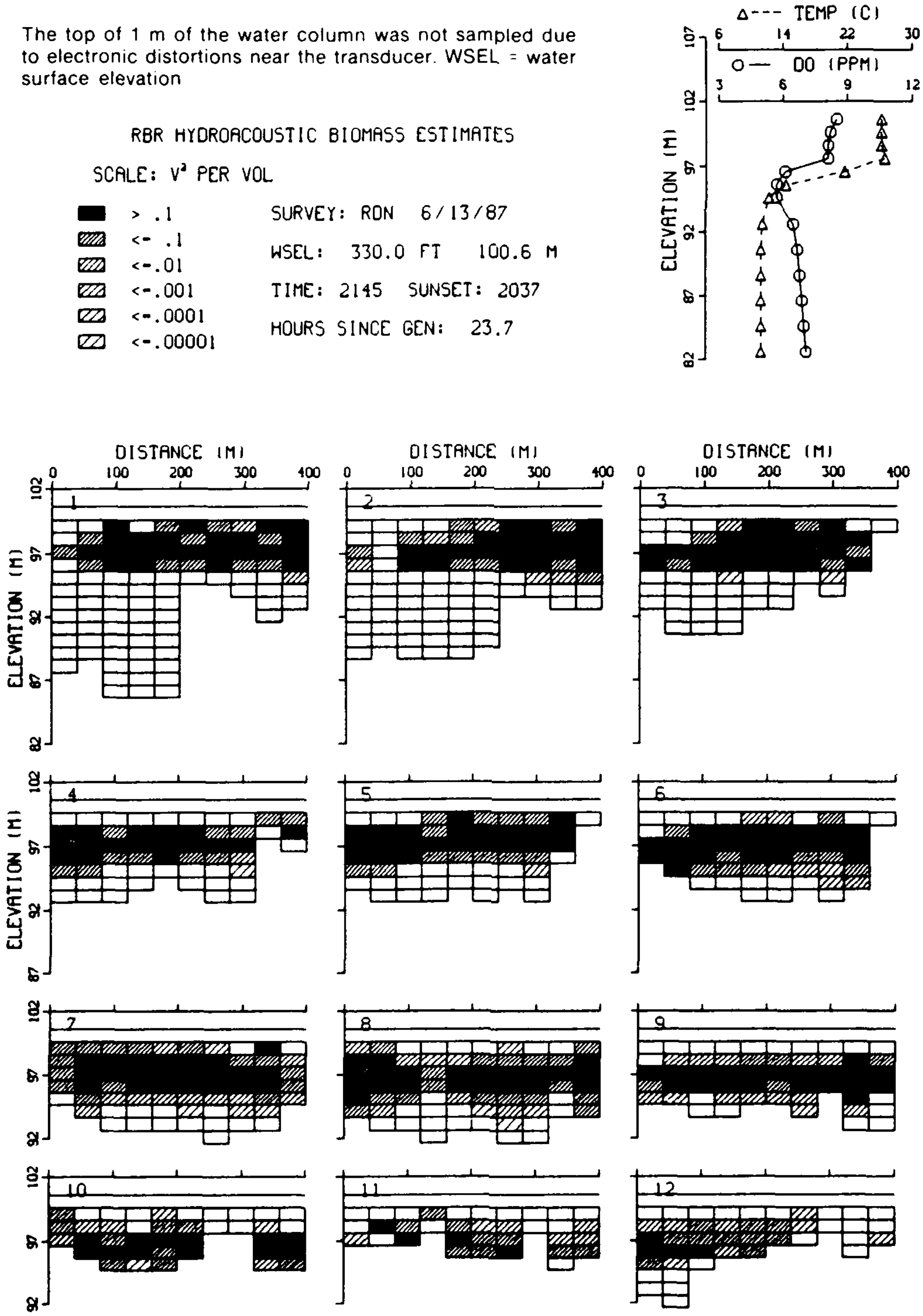

Figure 58. Vertical and lateral distribution of relative fish biomass during the night moratorium survey (RDN) conducted on 13 June 1987. Temperature and dissolved oxygen profiles are presented along with other information. Different shadings represent order of magnitude differences in fish biomass

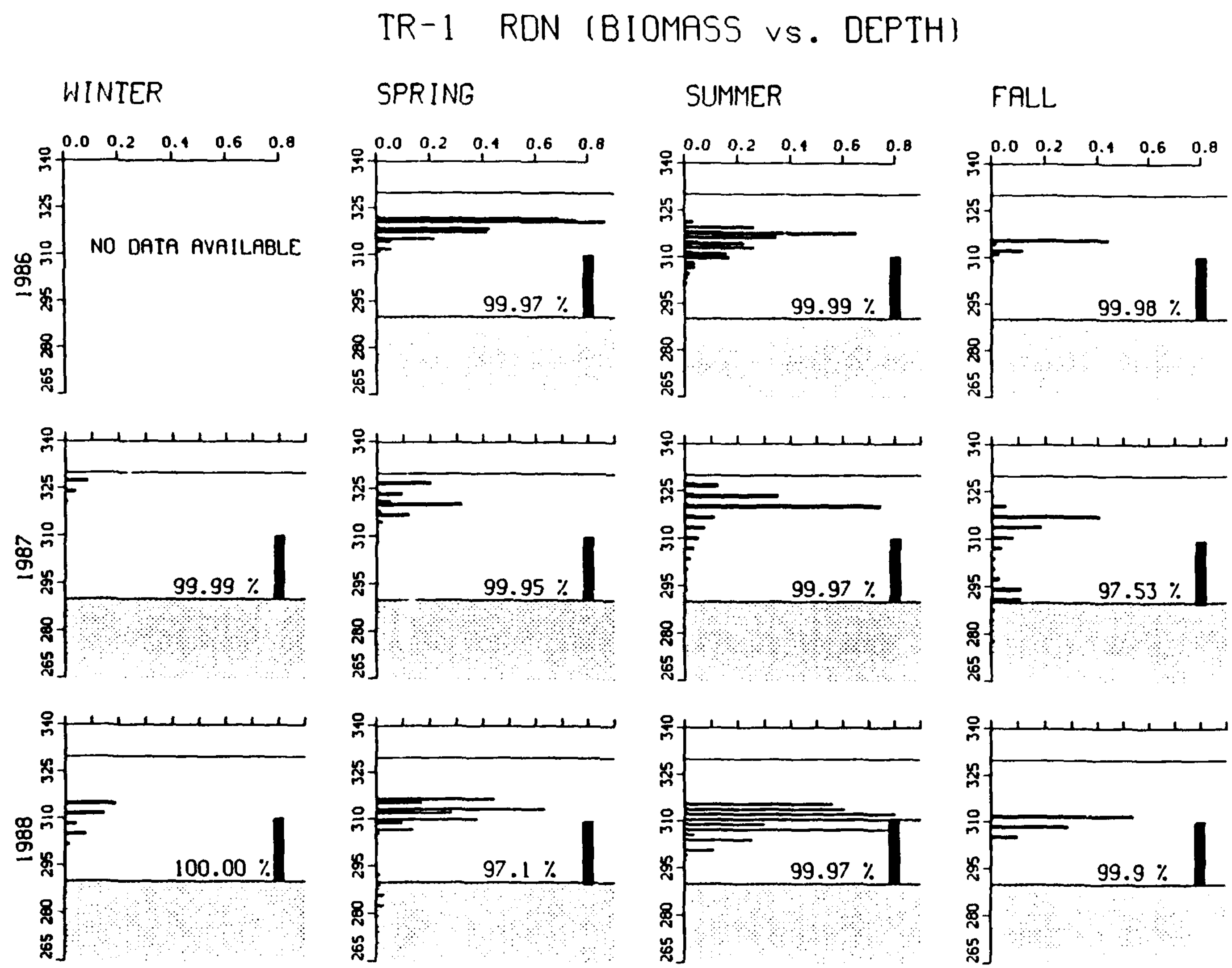

Figure 59. Depth distribution of fish biomass by season and year in the RBR tailrace. Horizontal bars in each frame show the sum of biomass values for each depth stratum for the 3 months comprising that season and year. The lower third of each frame is shaded to indicate the level of the draft tube openings. The single vertical bar in each frame indicates the percent of fish biomass above or below the level of the draft tube openings

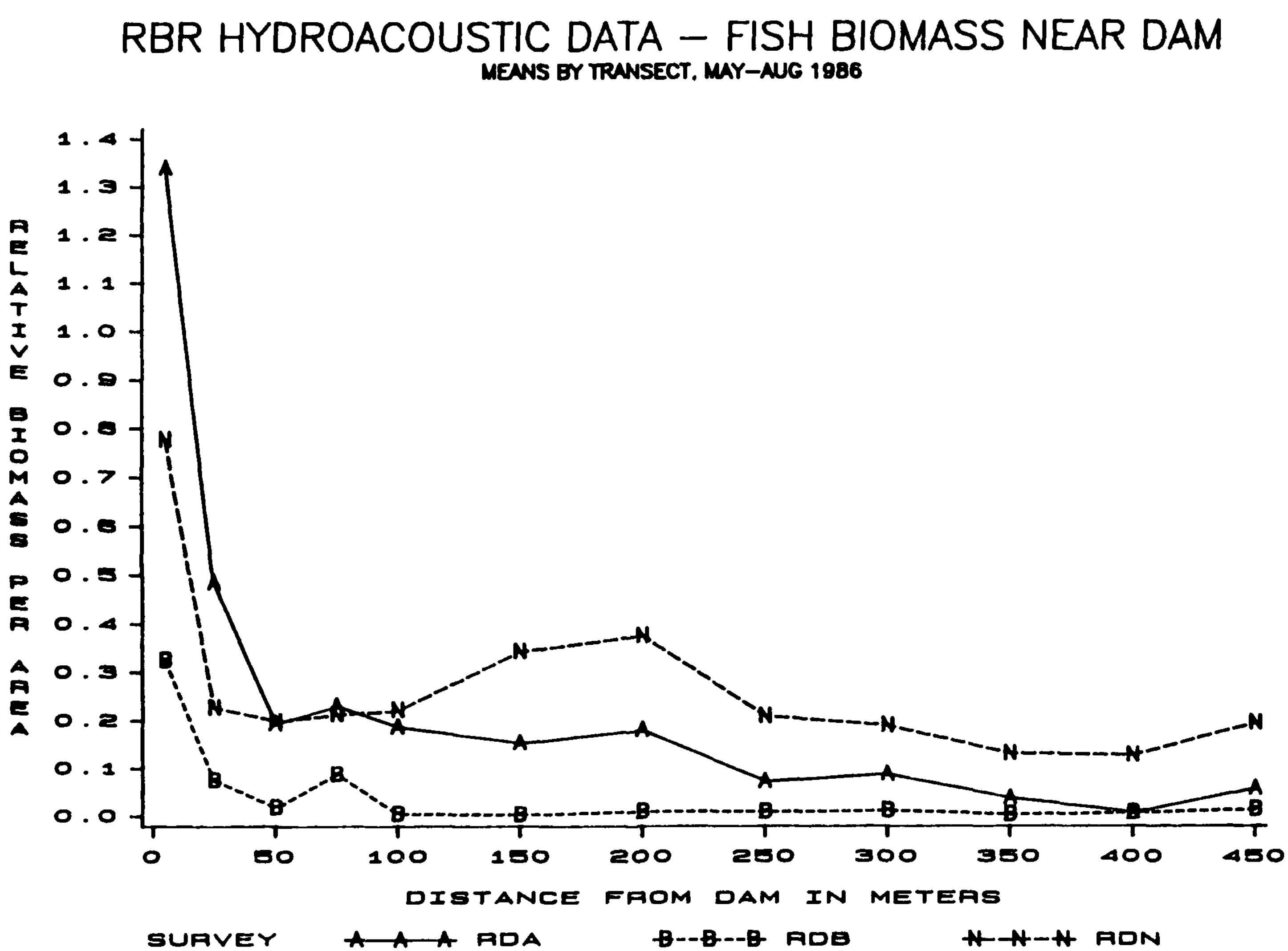

Figure 60. Relative fish biomass distribution in 1986 with distance from RBR Dam for postgeneration periods (RDA), pregeneration daytime periods (RDB), and nongeneration periods at night (RDN). Each point represents the mean of each transect for all surveys conducted from May through August 1986

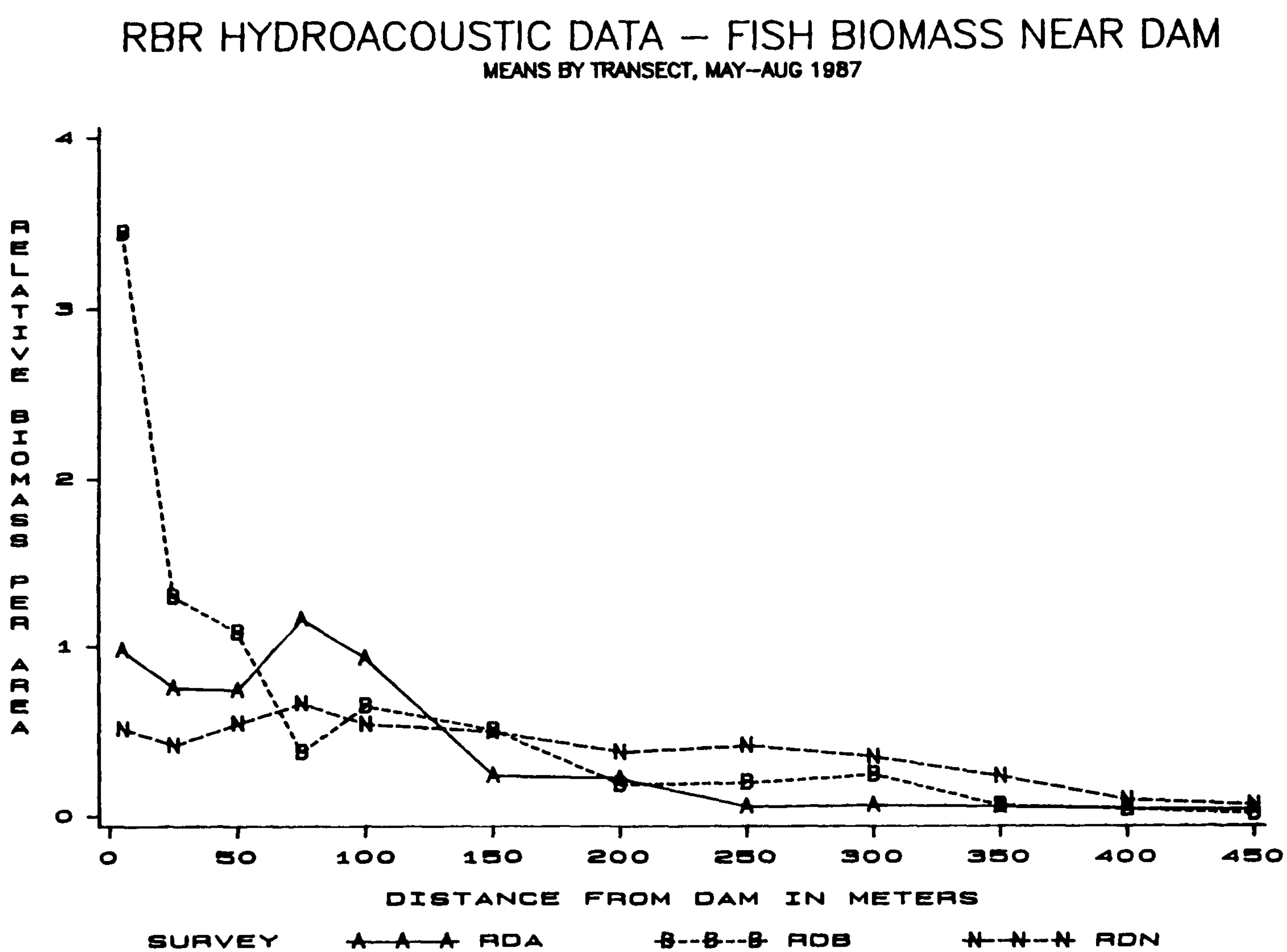

Figure 61. Relative fish biomass distribution in 1987 with distance from RBR Dam for postgeneration periods (RDA), pregeneration daytime periods (RDB), and nongeneration periods at night (RDN). Each point represents the mean of each transect for all surveys conducted from May through August 1987

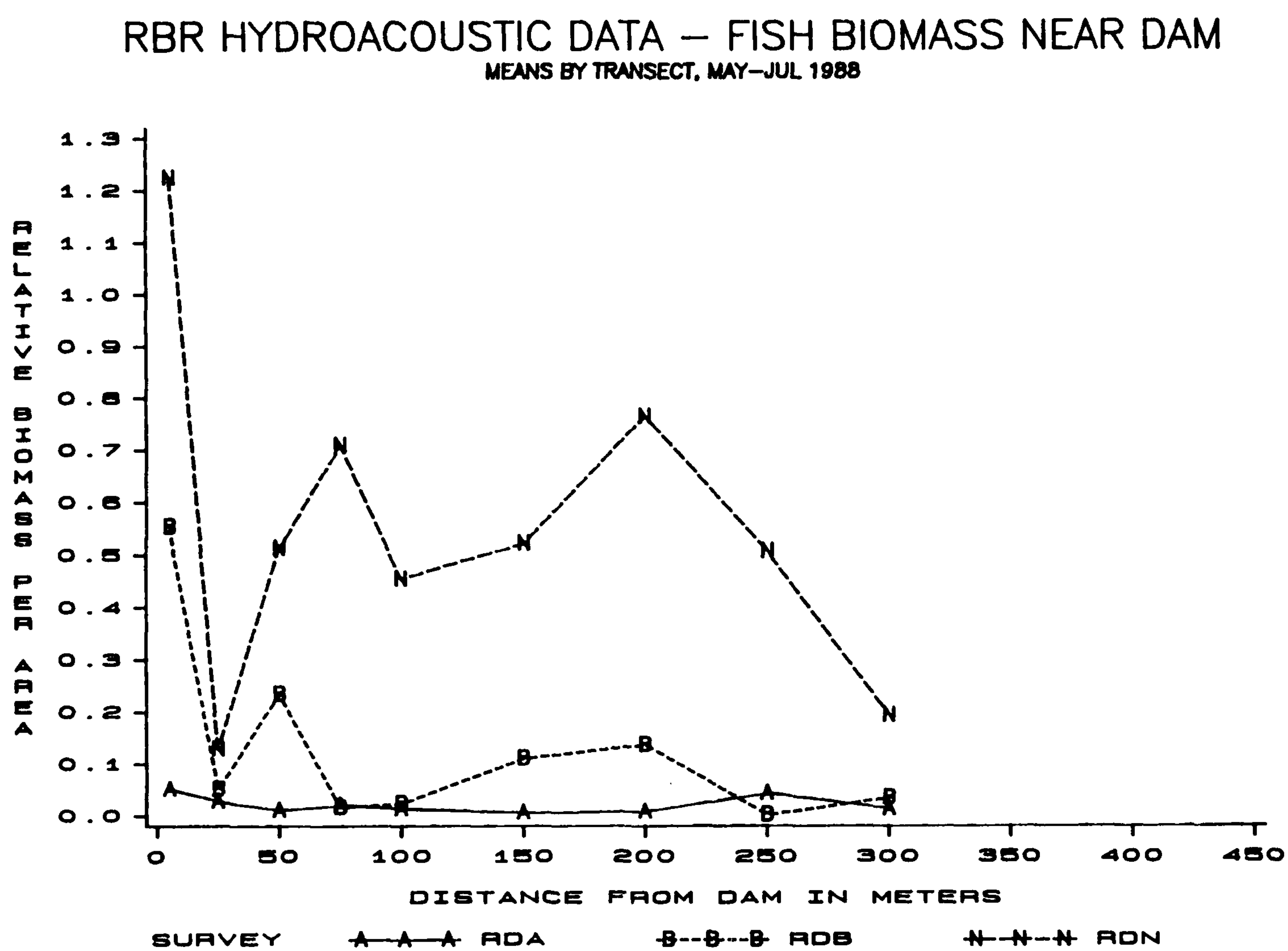

Figure 62. Relative fish biomass distribution in 1988 with distance from RBR dam for postgeneration periods (RDA), pregeneration daytime periods (RDB), and nongeneration periods at night (RDN). Each point represents the mean of each transect for all surveys conducted from May through July 1988

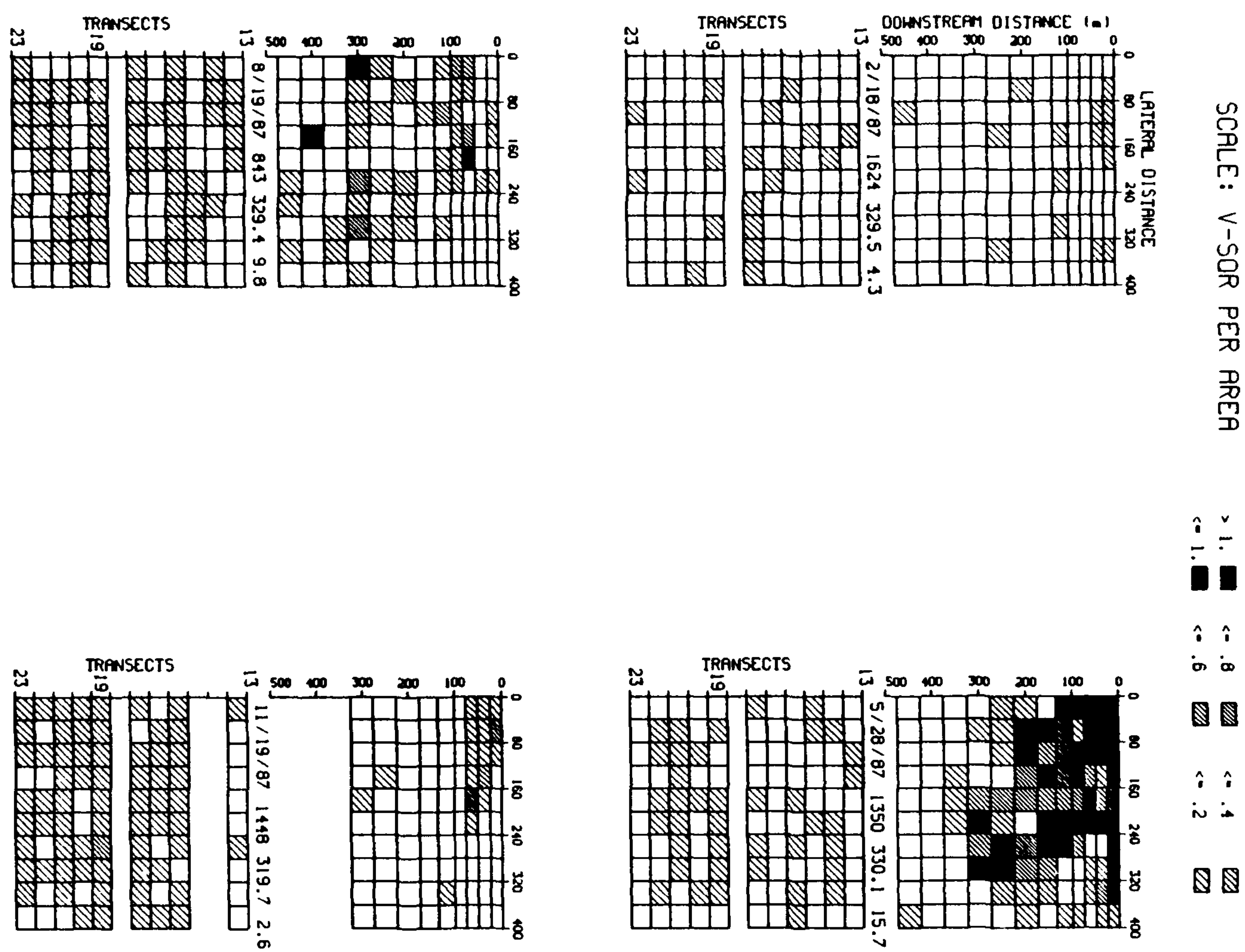

Figure 63. Areal fish biomass distribution in the RBR tailrace and tailwater during the day in 1987. Each frame displays a seasonally representative distribution in the tailrace (0 to 500 m from the dam) and a corresponding distribution in the tailwater (Transects 13-23), usually within 1 day of the tailrace survey. The date, time, water surface elevation in feet, and time since generation are indicated for the tailrace portion of each frame

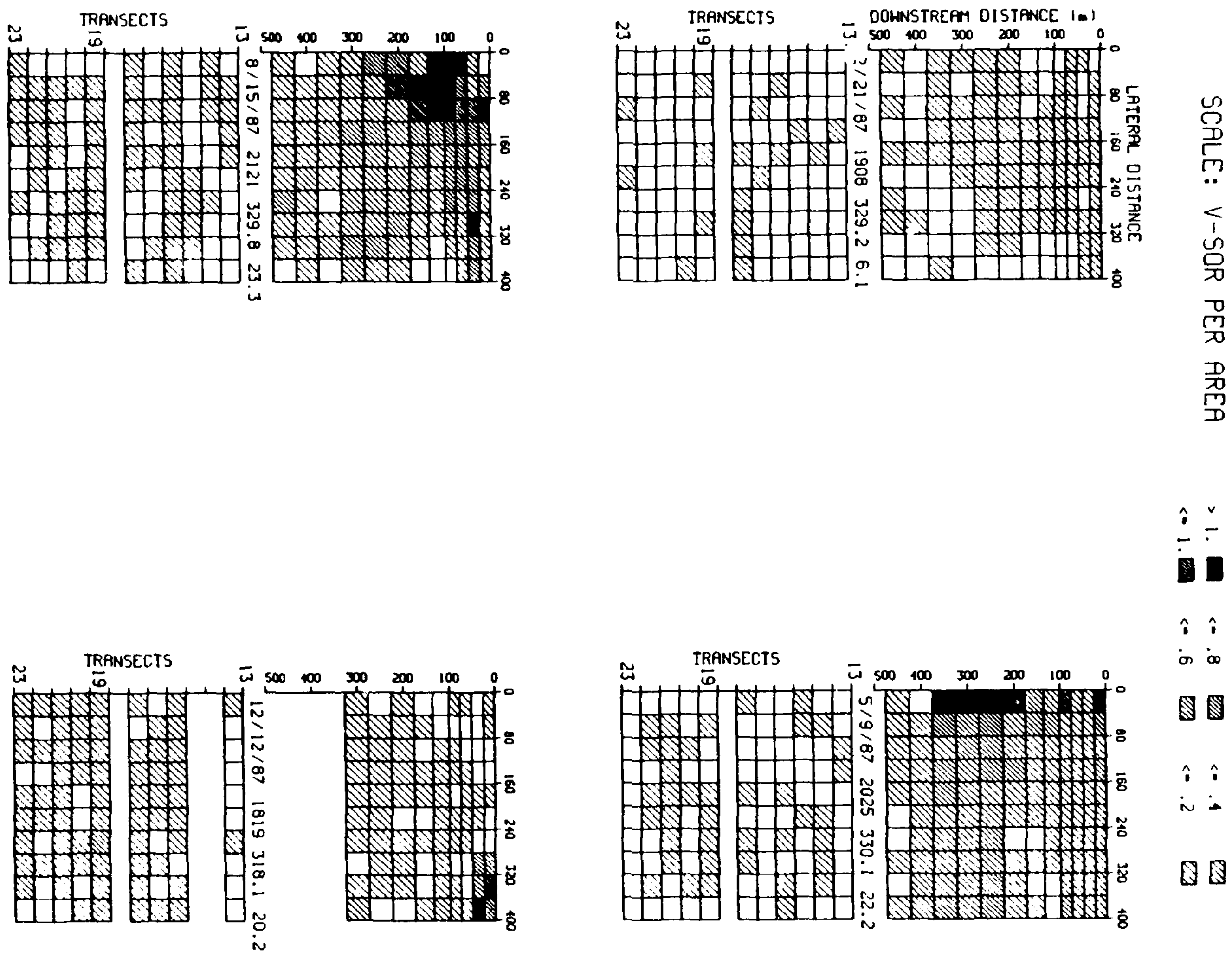

Figure 64. Areal fish biomass distribution in the RBR tailrace at night and tailwater during the day in 1987. Each frame displays a seasonally representative distribution in the tailrace (0 to 500 m from the dam) and a corresponding distribution in the tailwater (Transects 13-23), usually within 24 hr of the tailrace survey. The date, time, water surface elevation in feet, and time since generation are indicated for the tailrace portion of each frame

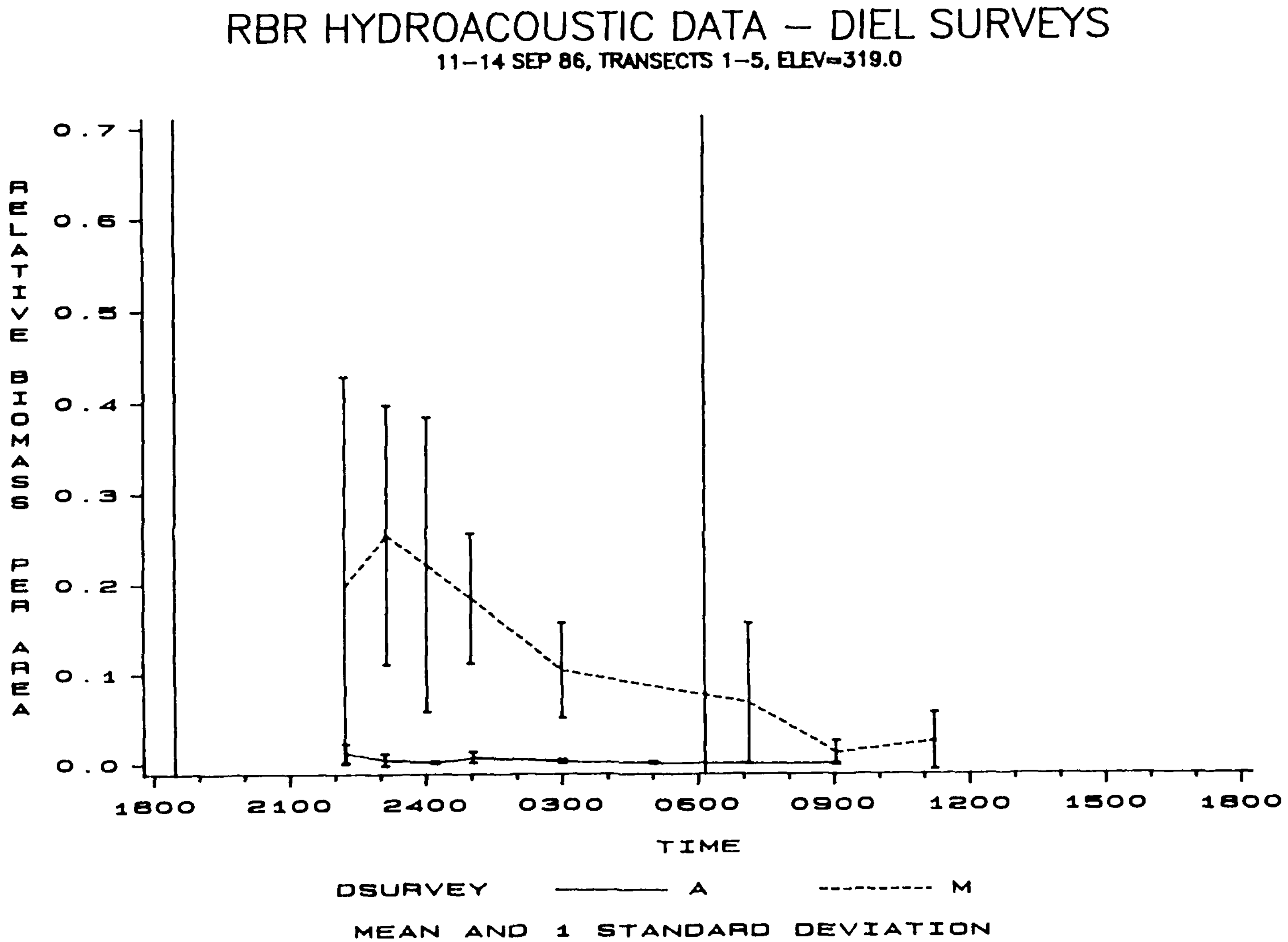

Figure 65. Diel patterns of fish biomass in the RBR tailrace, September 1986, for a postgeneration period (11-12 Sep: A) and a moratorium period (13-14 Sep: M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

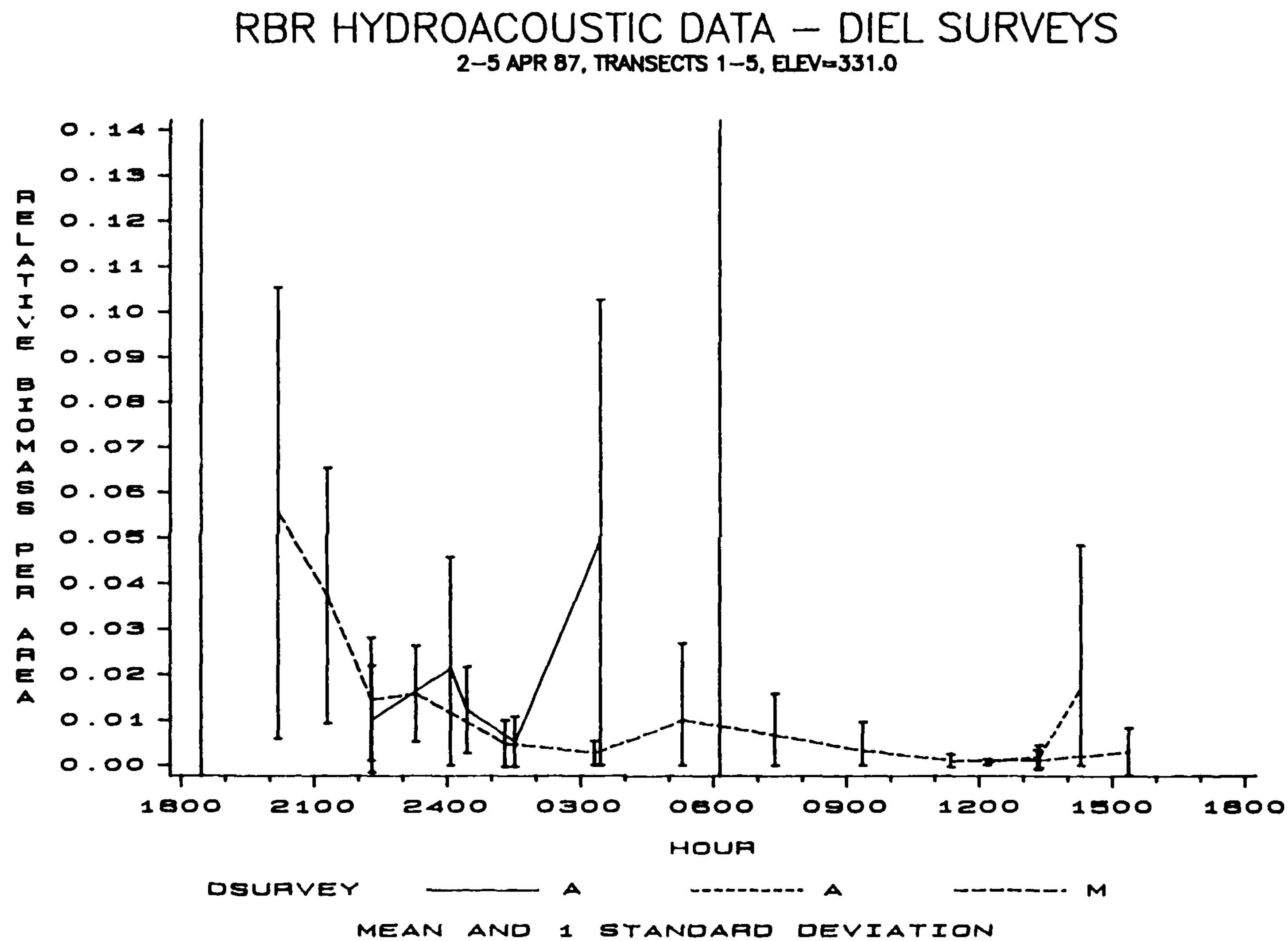

Figure 66. Diel patterns of fish biomass in the RBR tailrace, April 1987, for a post-generation period (2-3 Apr: A) and a moratorium period (4-5 Apr: M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

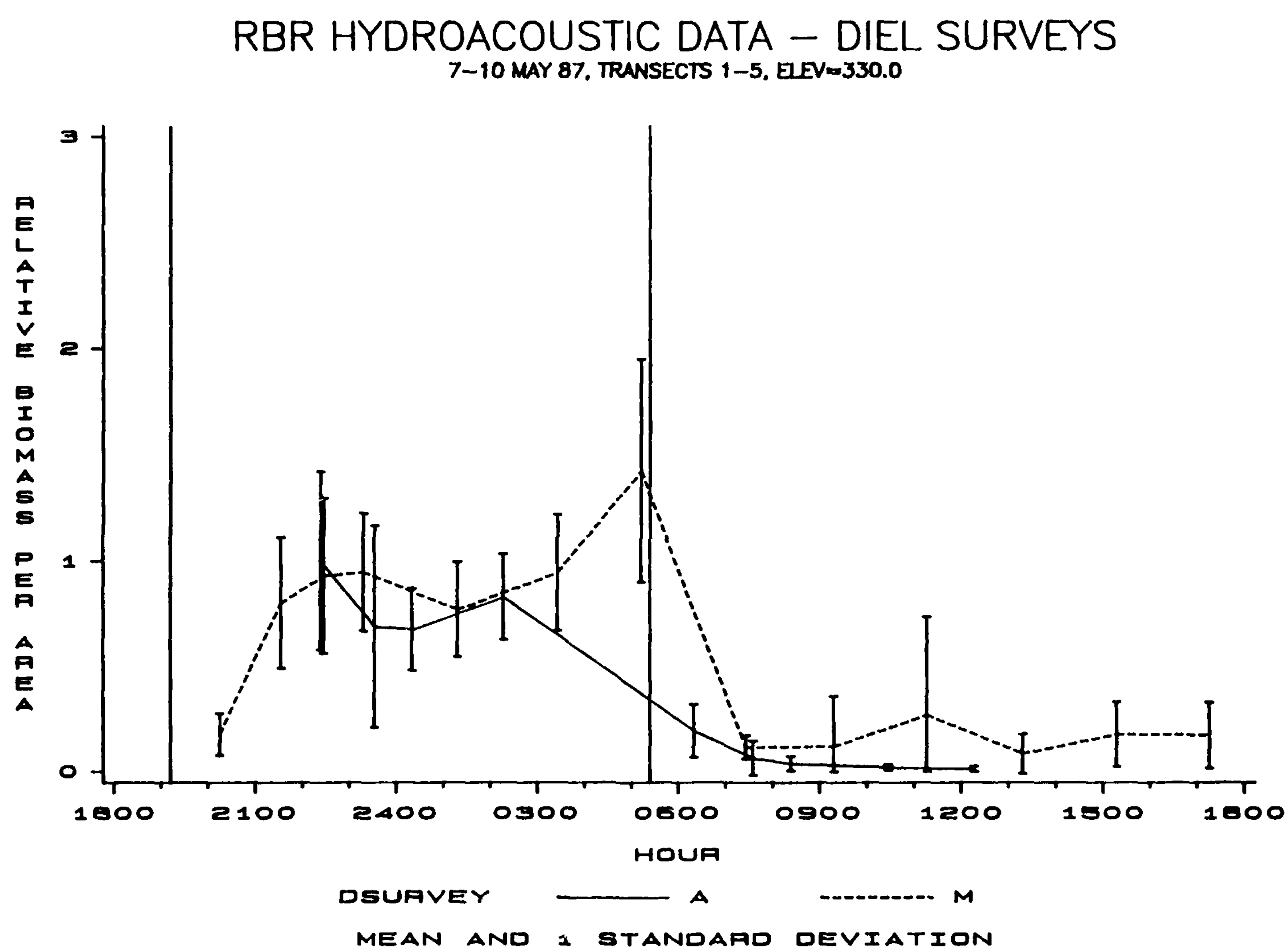

Figure 67. Diel patterns of fish biomass in the RBR tailrace, May 1987, for a postgeneration period (7-8 May: A) and a moratorium period (9-10 May: M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

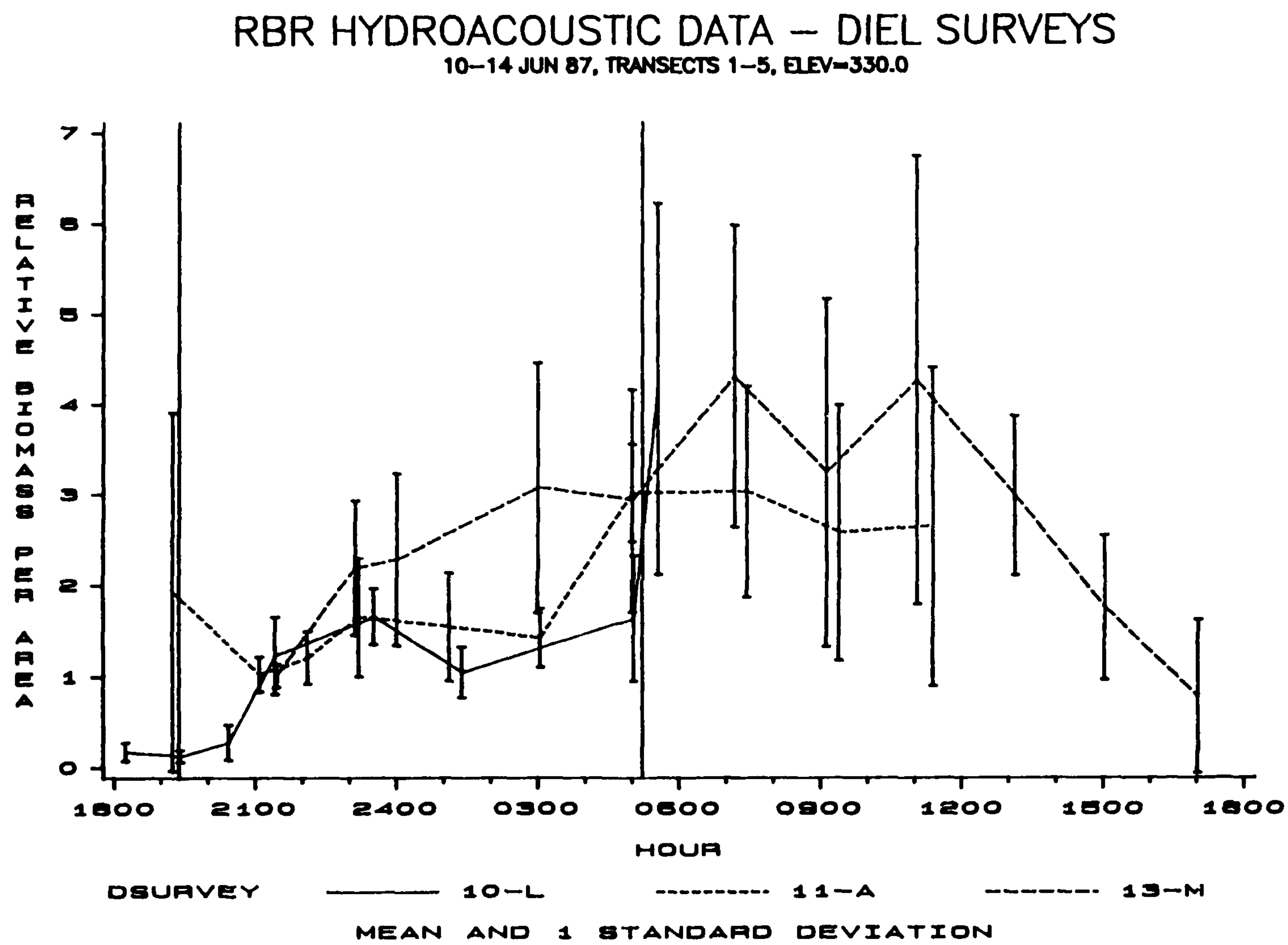

Figure 68. Diel patterns of fish biomass in the RBR tailrace, June 1987, for a post-generation period with lights off (10-11 Jun: 10-L), a postgeneration period with the lights on (11-12 Jun: 11-A), and a moratorium period (13-14 Jun: 13-M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

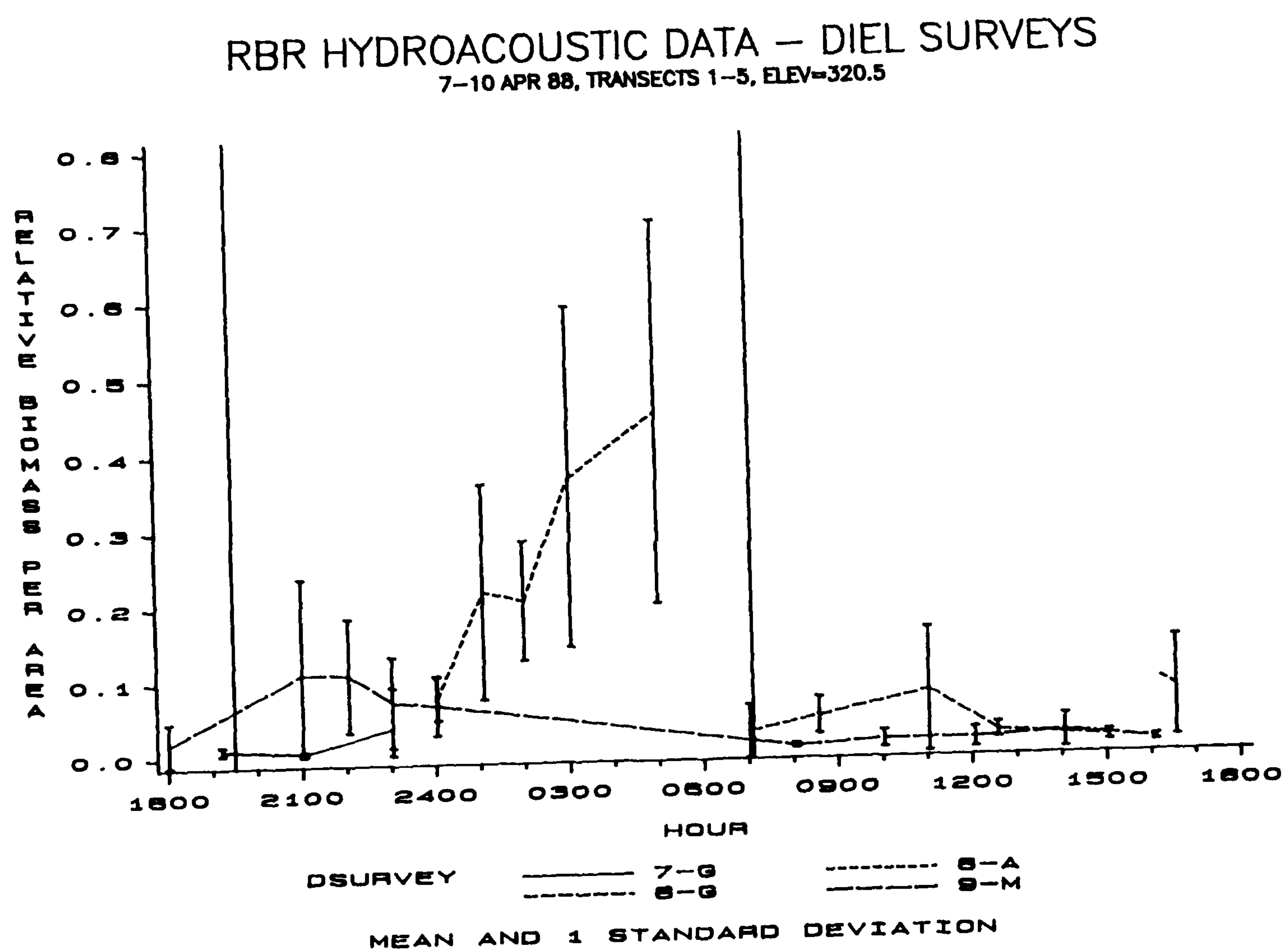

Figure 69. Diel patterns of fish biomass in the RBR tailrace, April 1988, for generation periods (7 Apr: 7-G, 8 Apr: 8-G), a postgeneration period (8 Apr: 8-A), and a moratorium period (9-10 Apr: 9-M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

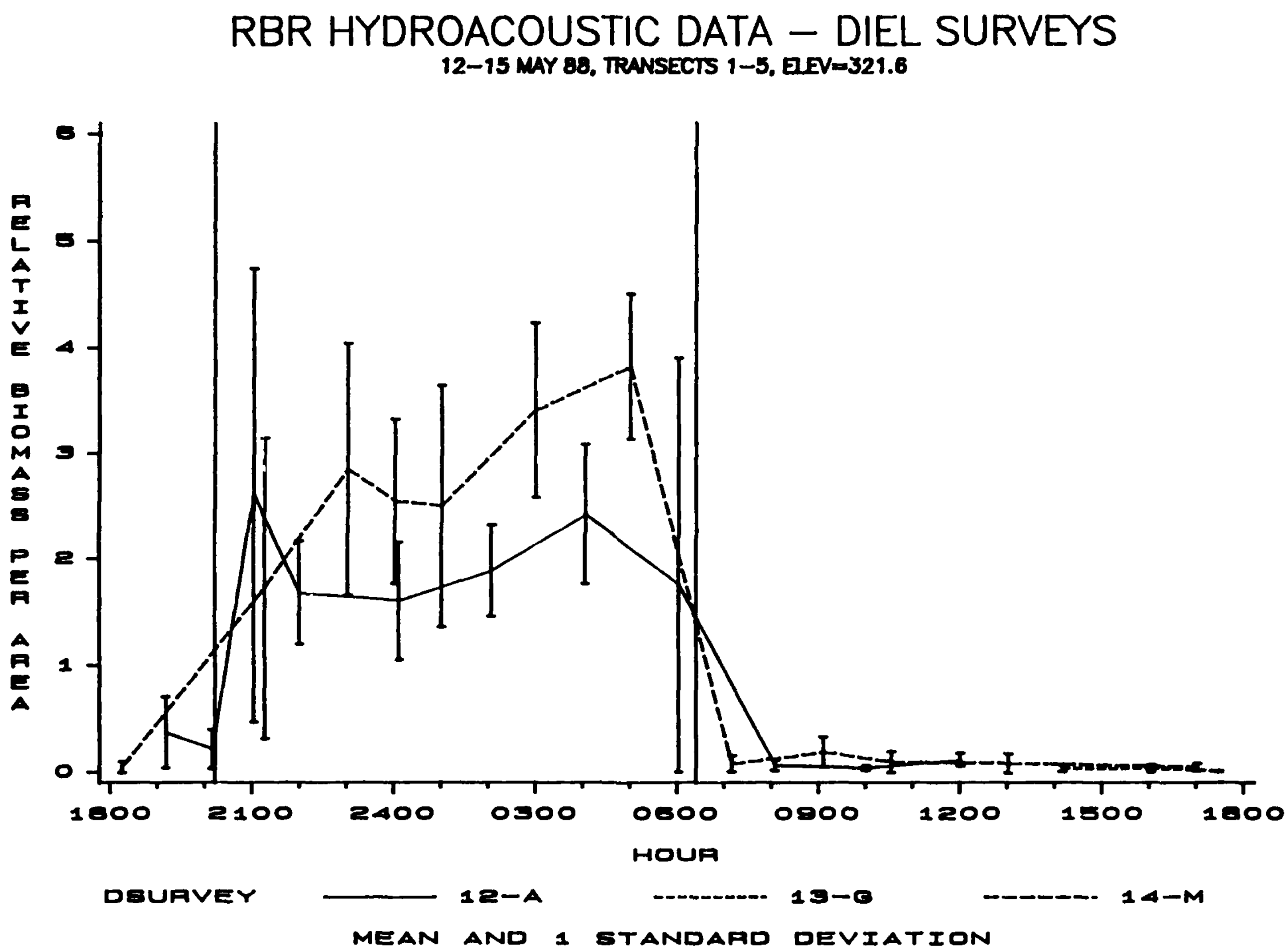

Figure 70. Diel patterns of fish biomass in the RBR tailrace, May 1988, for a postgeneration period (12-13 May: 12-A), a generation period (13 May: 13-G), and a moratorium period (14-15 May: 14-M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

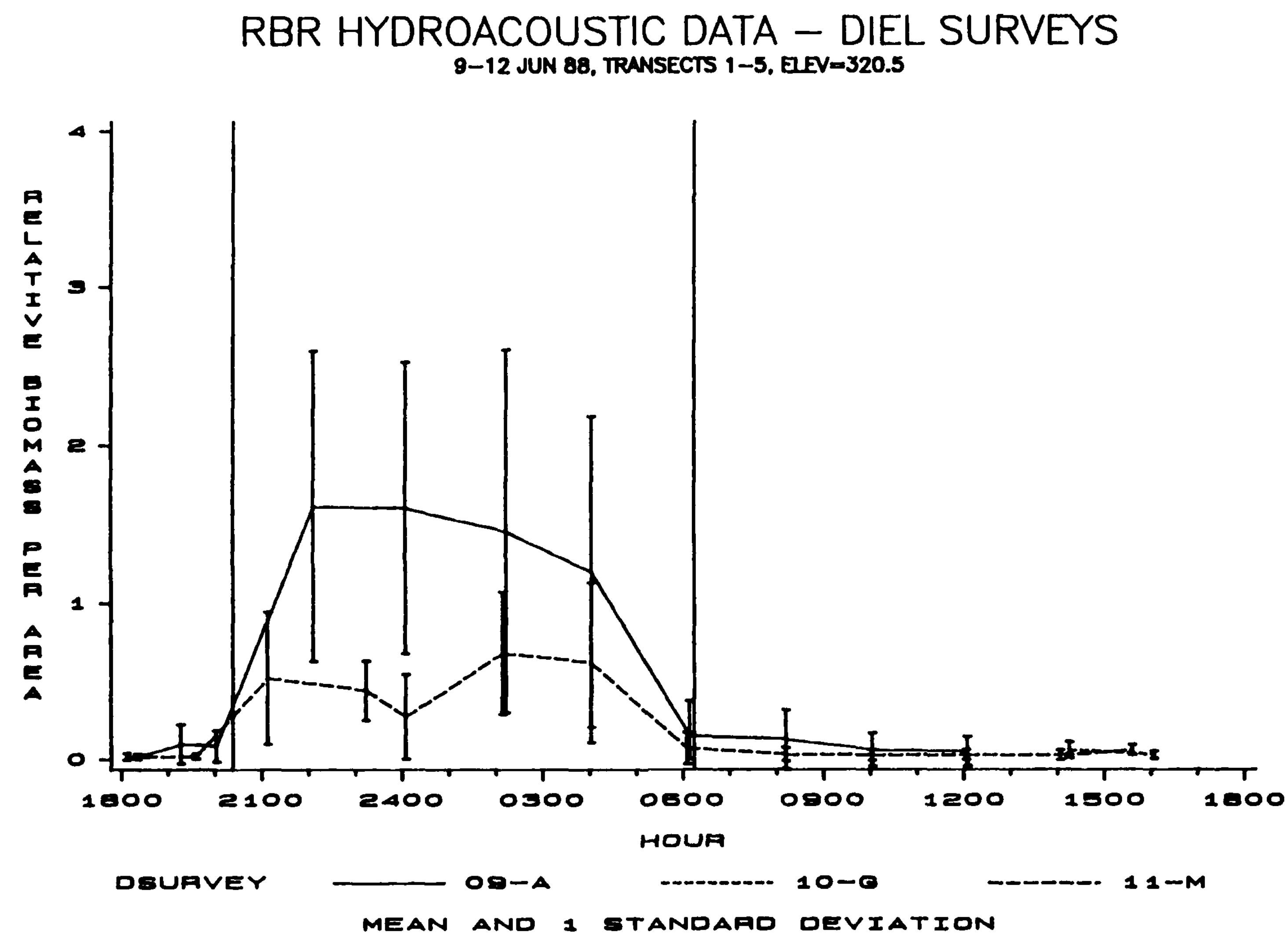

Figure 71. Diel patterns of fish biomass in the RBR tailrace, June 1988, for a post-generation period (9-10 Jun: 9-A), a generation period (10 Jun: 10-G), and a moratorium period (11-12 Jun: 11-M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

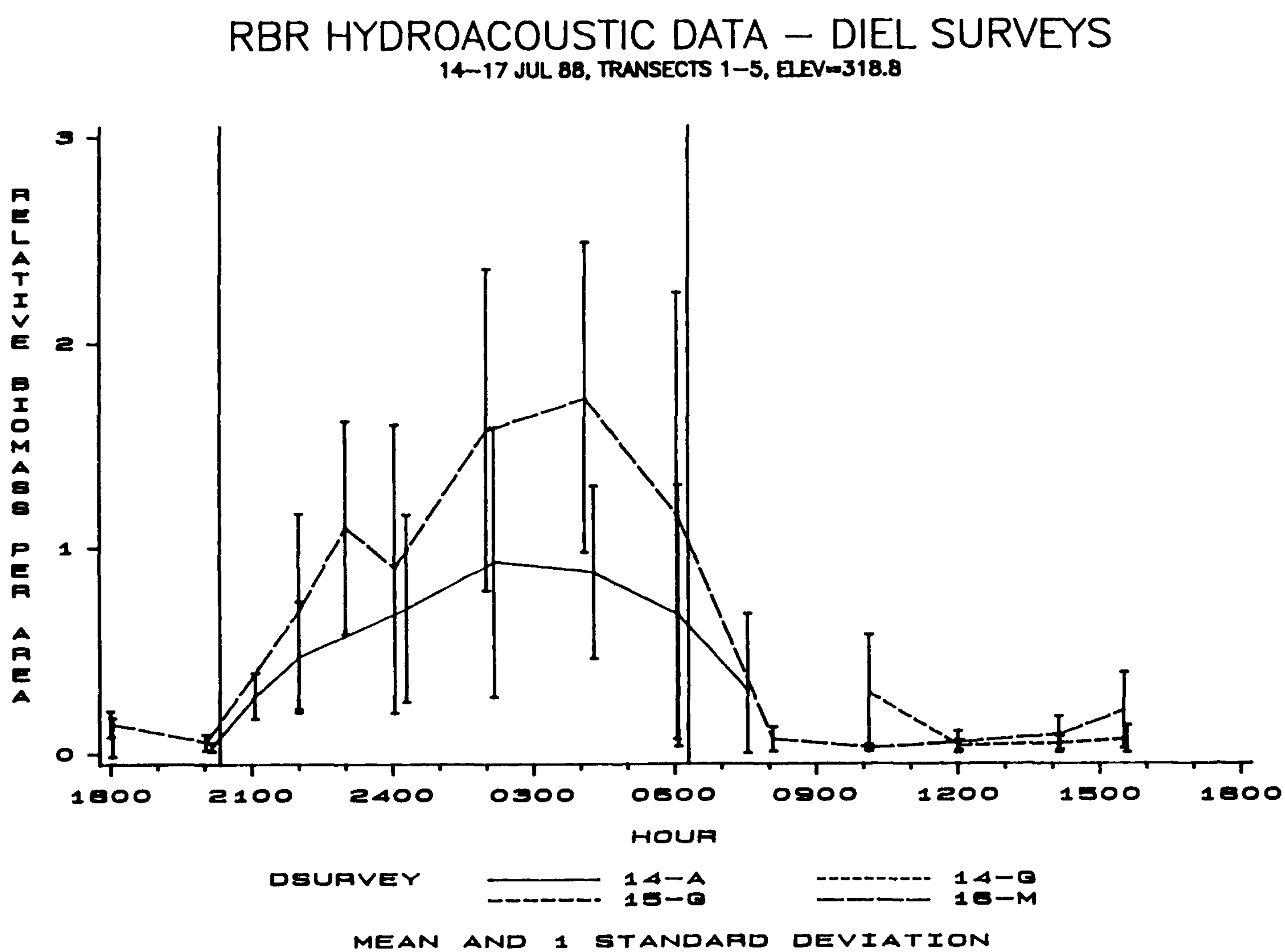

Figure 72. Diel patterns of fish biomass in the RBR tailrace, July 1988, for generation periods (14 Jul: 14-G, 15 Jul: 15-G), a postgeneration period (14-15 Jul: 14-A), and a moratorium period (16-17 Jul: 16-M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

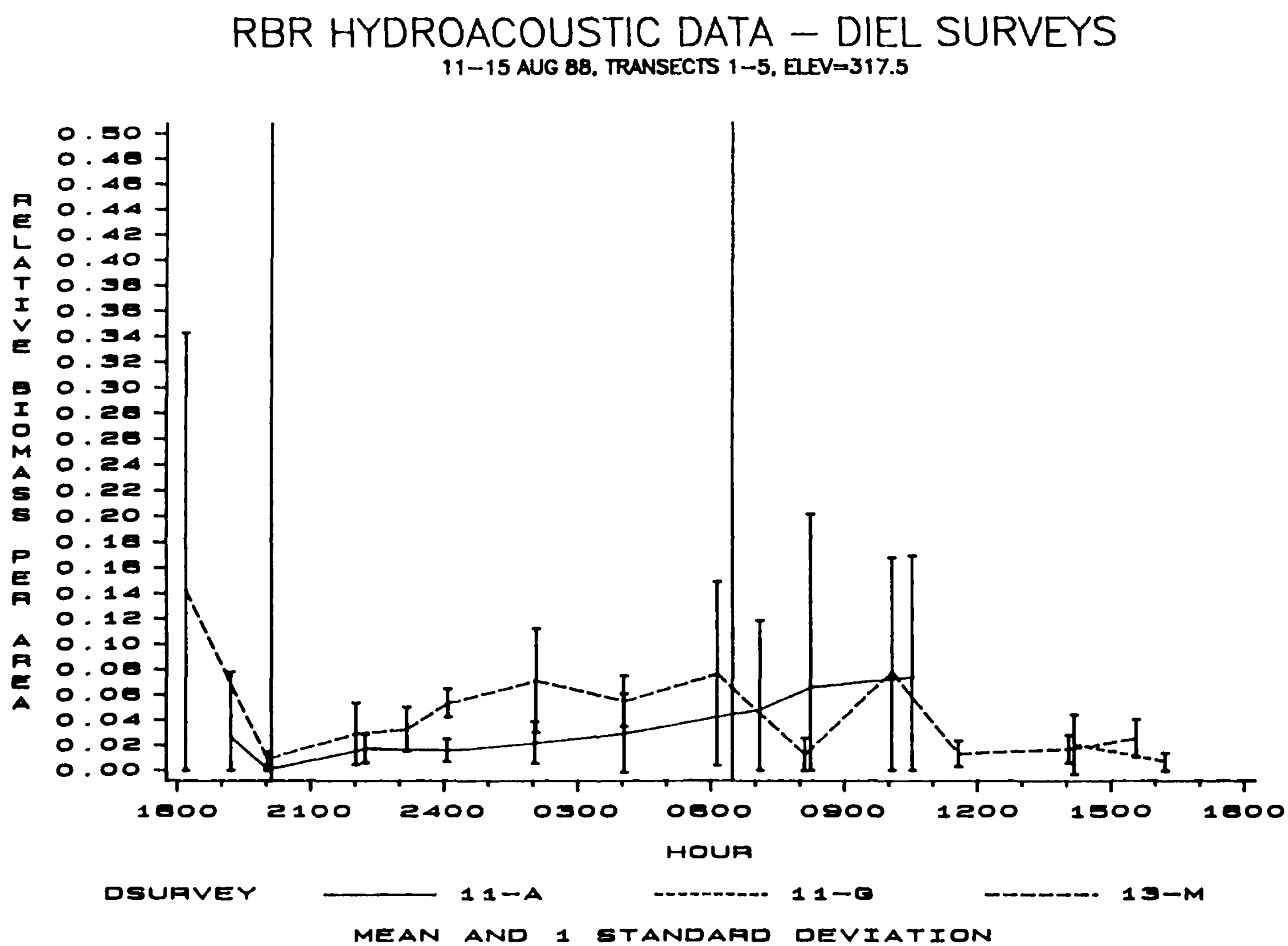

Figure 73. Diel patterns of fish biomass in the RBR tailrace, August 1988, for a post-generation period (11-12 Aug: 11-A), a generation period (12 Aug: 11-G), and a moratorium period (13-14 Aug: 13-M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

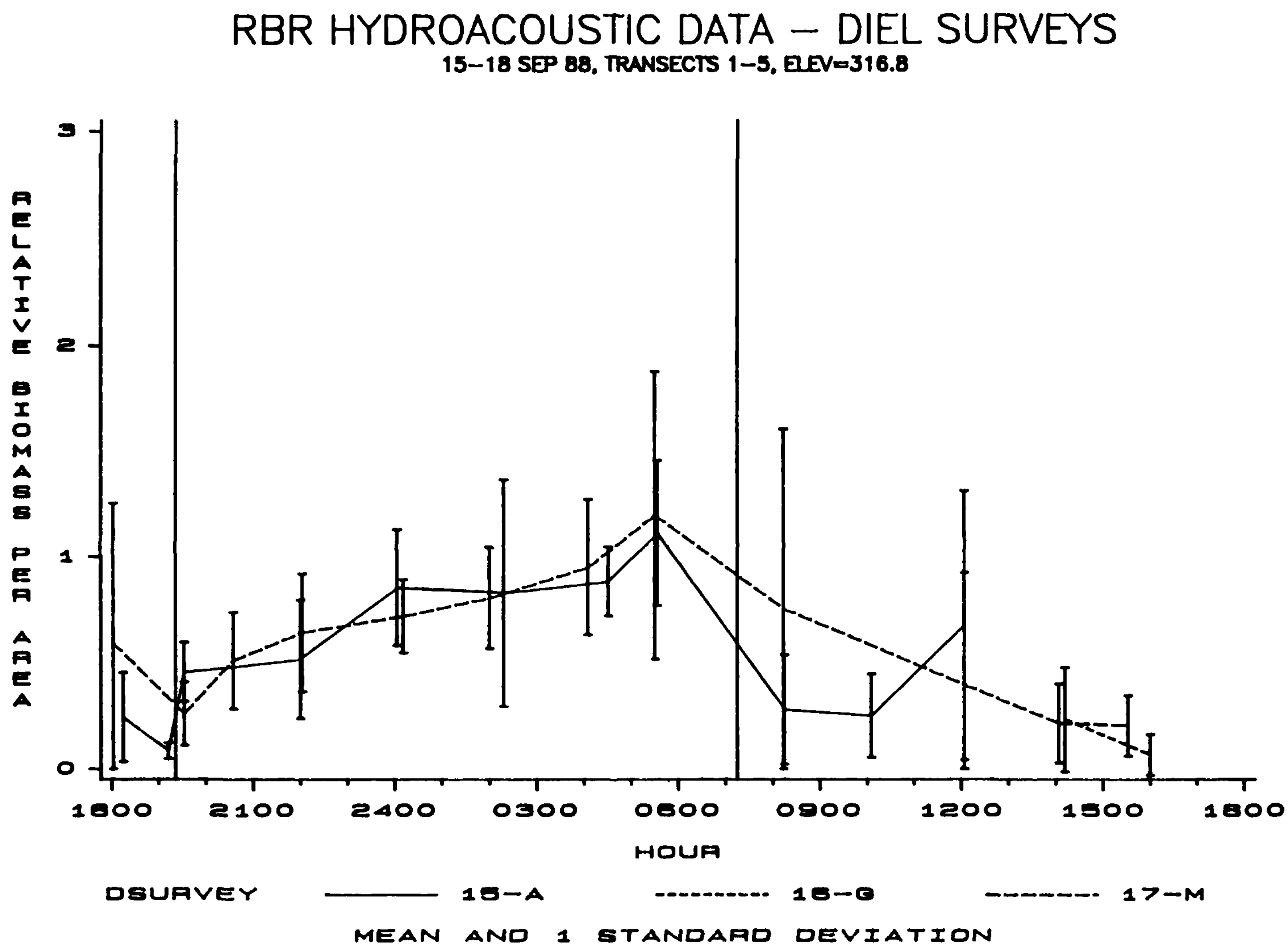

Figure 74. Diel patterns of fish biomass in the RBR tailrace, September 1988, for a postgeneration period (15-16 Sep: 15-A), a generation period (16 Sep: 16-G), and a moratorium period (17-18 Sep: 17-M). Shown are means of Transects 1-5 ± 1 SD. Vertical lines indicate the approximate time of sunrise and sunset

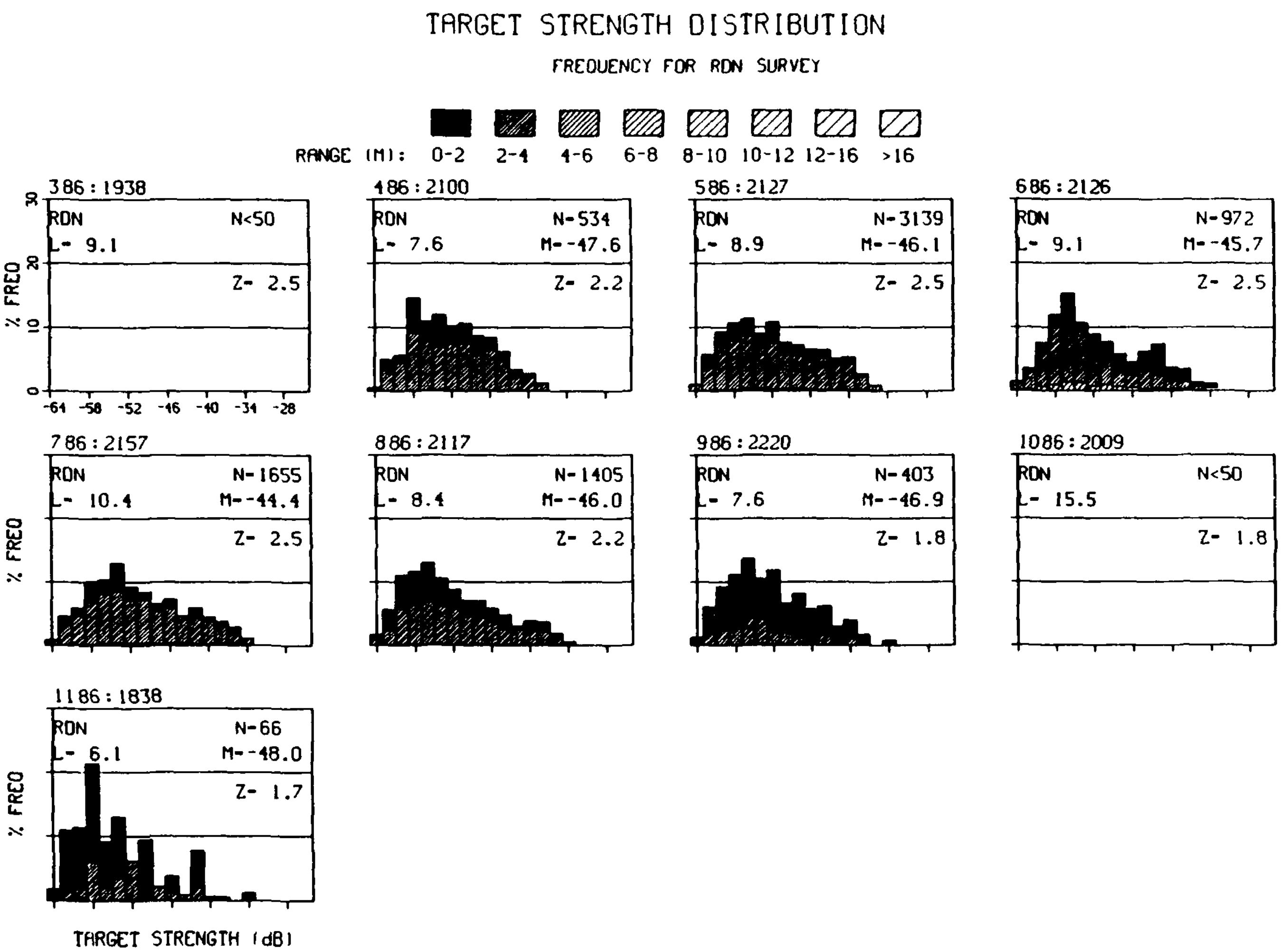

Figure 75. Target strength frequency distribution by month for nighttime tailrace (RDN) surveys in 1986. Month, year, and sample start time are indicated above each frame. If the number of single targets (N) was <50, the histogram was not plotted; M = mean target strength (DB); L = mean length (cm), based on Love (1977); Z = mean depth of targets (m), weighted by 1/(range squared)

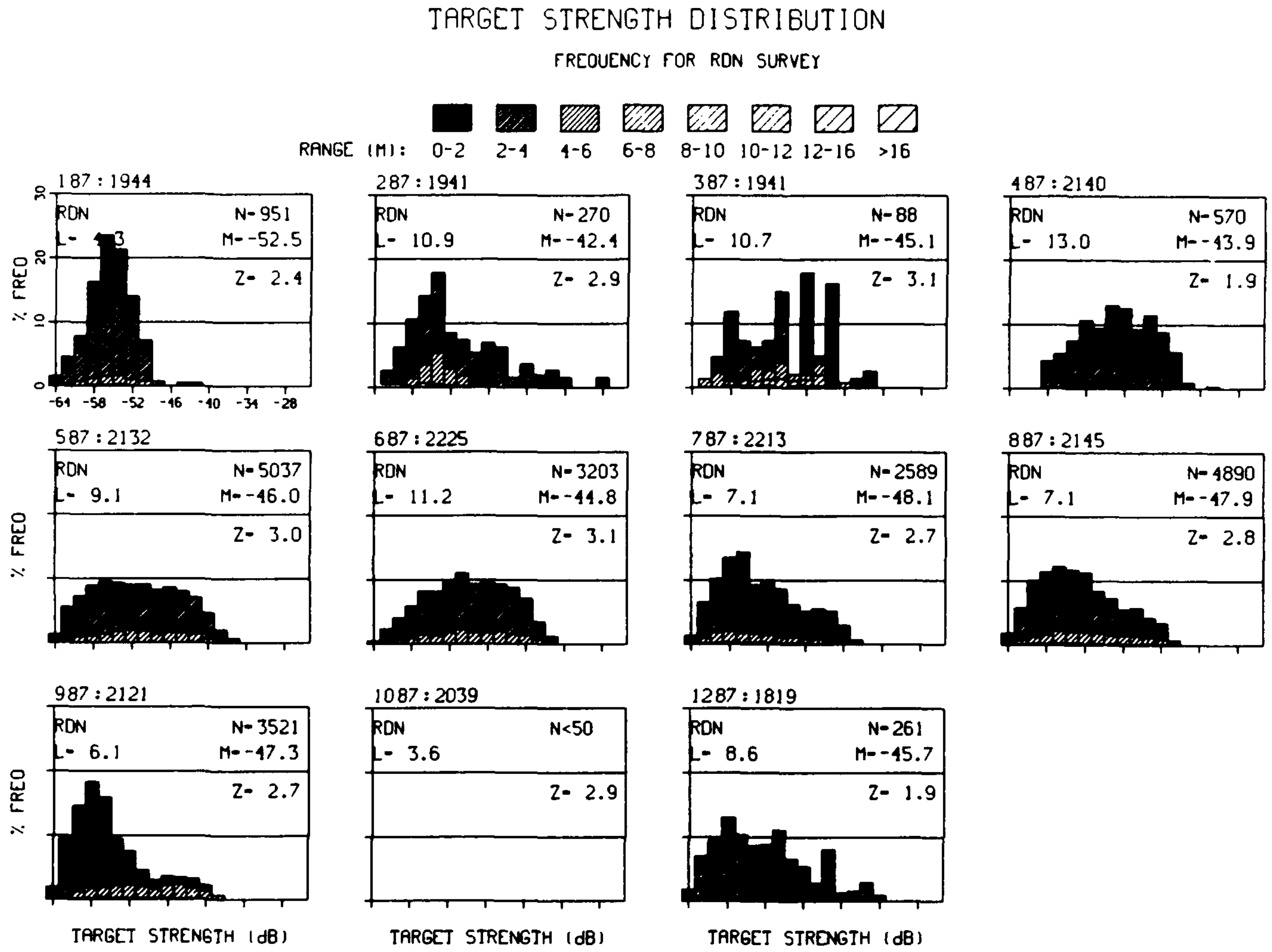

Figure 76. Target strength frequency distribution by month for nighttime tailrace (RDN) surveys in 1987. Month, year, and sample start time are indicated above each frame. If the number of single targets (N) was <50, the histogram was not plotted; M - mean target strength (DB); L - mean length (cm), based on Love (1977); Z - mean depth of targets (m), weighted by 1/(range squared)

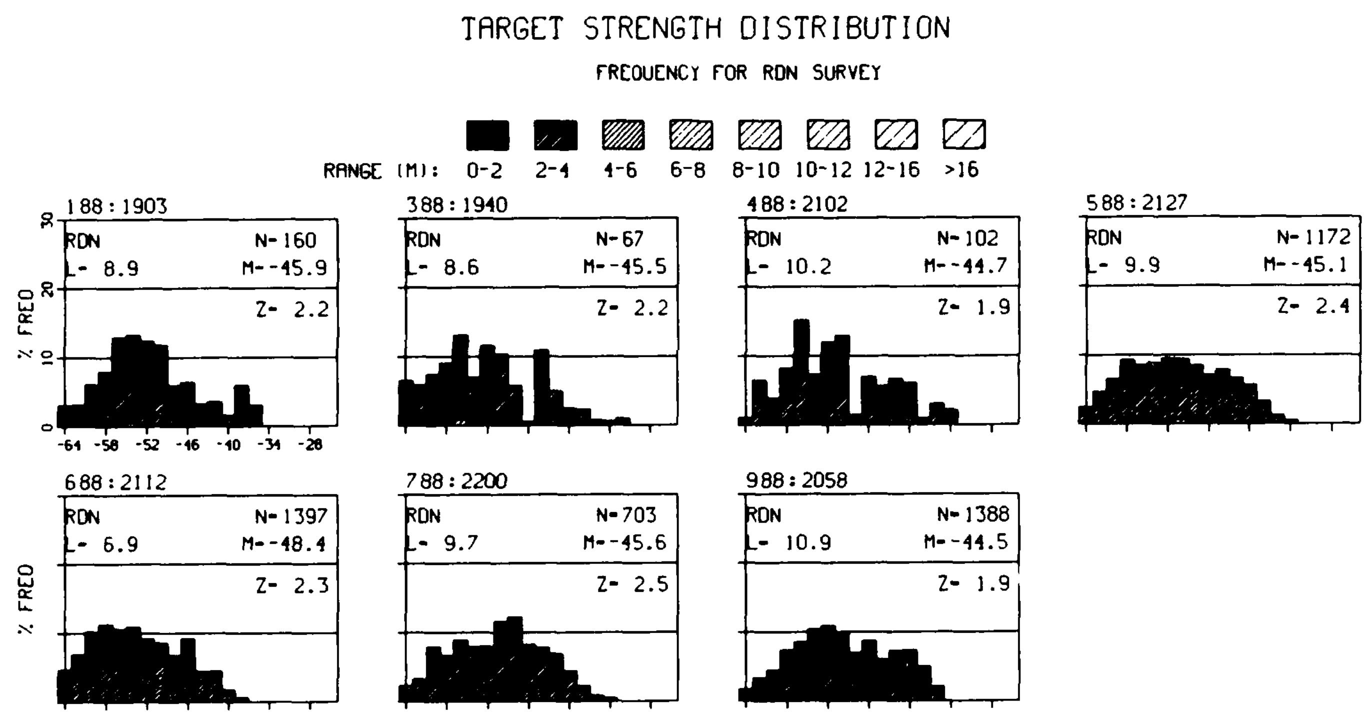

Figure 77. Target strength frequency distribution by month for nighttime tailrace (RDN) surveys in 1988. Month, year, and sample start time are indicated above each frame. If the number of single targets (N) was <50, the histogram was not plotted; M = mean target strength (DB); L = mean length (cm), based on Love (1977); Z = mean depth of targets (m), weighted by 1/(range squared)

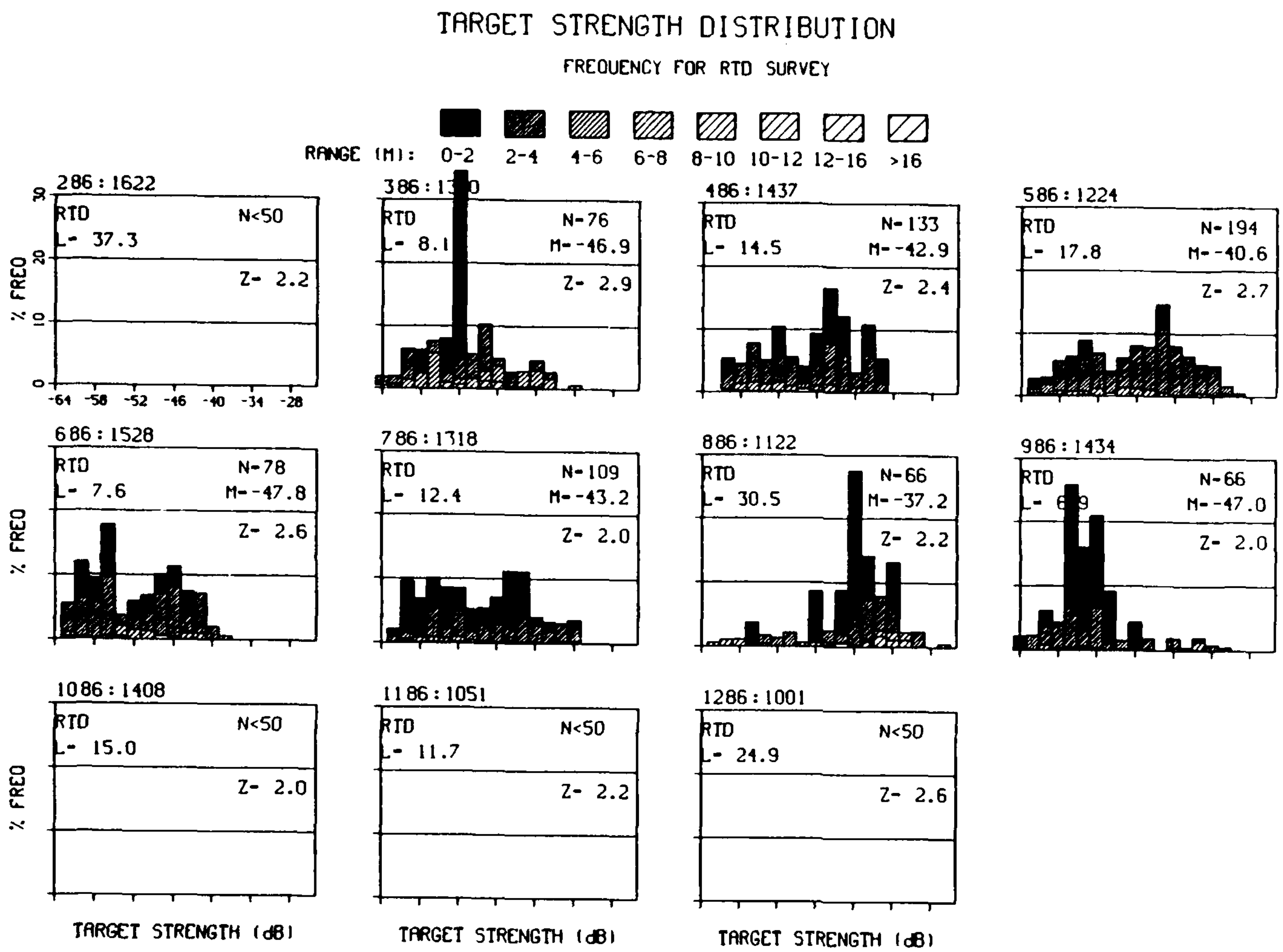

Figure 78. Target strength frequency distribution by month for daytime tailwater (RTD) surveys in 1986. Month, year, and sample start time are indicated above each frame. If the number of single targets (N) was <50, the histogram was not plotted; M = mean target strength (DB); L = mean length (cm), based on Love (1977); Z = mean depth of targets (m), weighted by 1/(range squared)

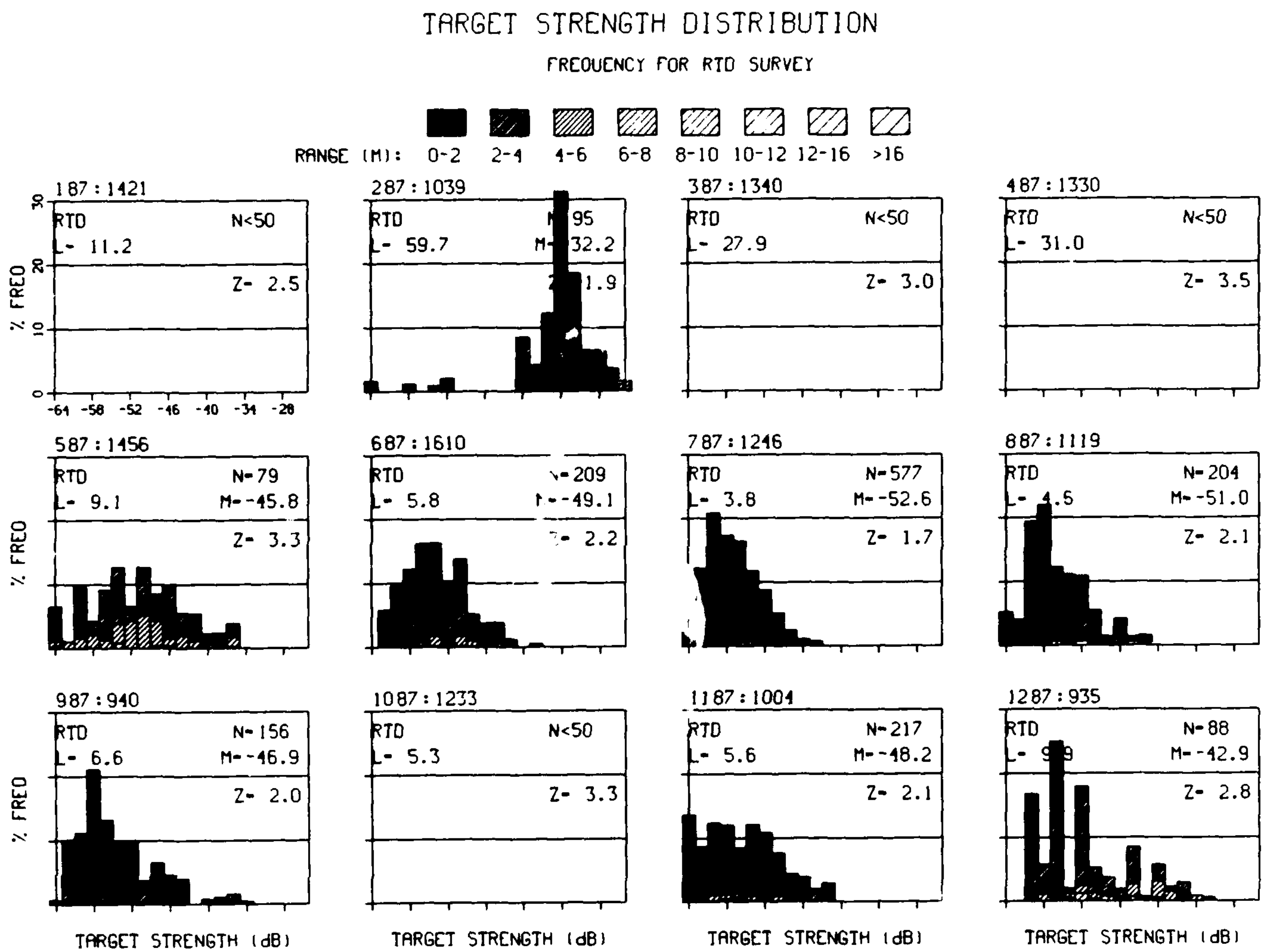

Figure 79. Target strength frequency distribution by month for daytime tailwater (RTD) surveys in 1987. Month, year, and sample start time are indicated above each frame. If the number of single targets (N) was <50, the histogram was not plotted; M - mean target strength (DB); L - mean length (cm), based on Love (1977); Z - mean depth of targets (m), weighted by 1/(range squared)

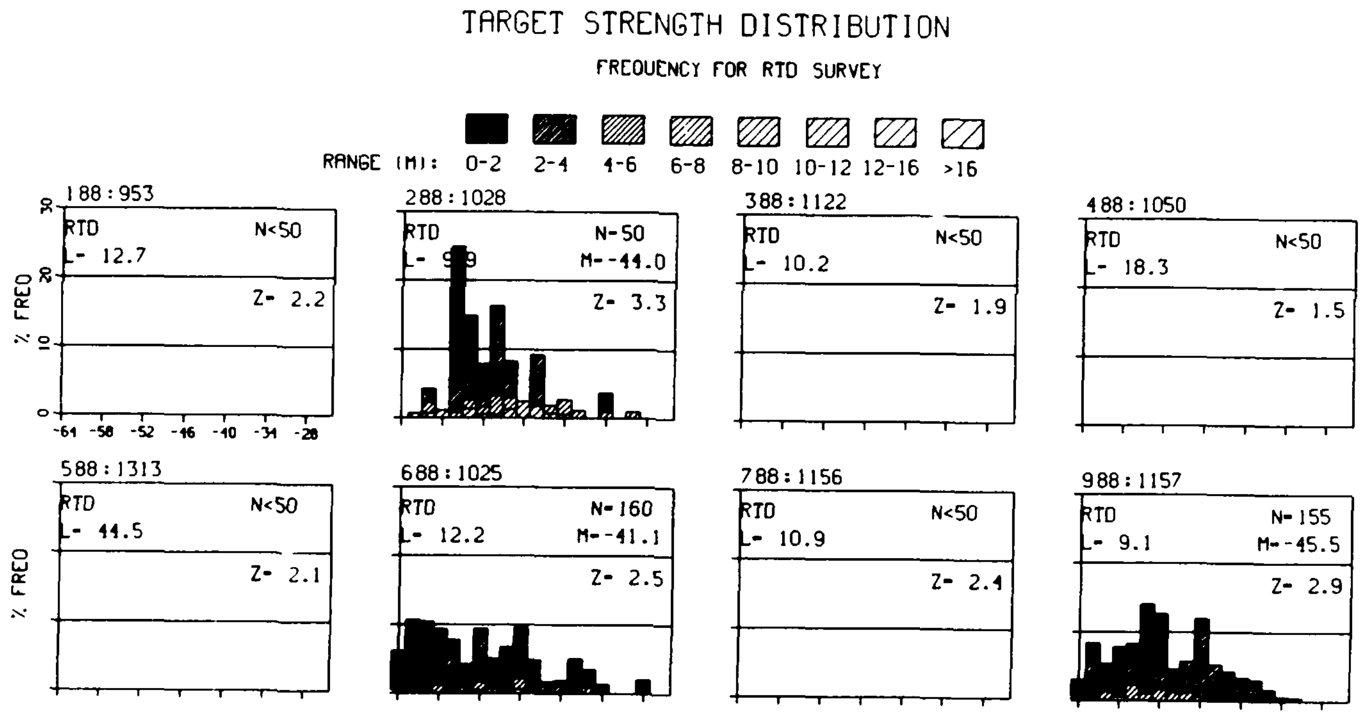

Figure 80. Target strength frequency distribution by month for daytime (RTD) or nighttime tailwater (RTD) surveys in 1987. Month, year, and sample start time are indicated above each frame. If the number of single targets (N) was <50, the histogram was not plotted; M - mean target strength (DB); L - mean length (cm), based on Love (1977); Z - mean depth of targets (m), weighted by 1/(range squared)

SPATIAL AND DIEL PATTERNS OF ICHTHYOPLANKTON
ABUNDANCE WITHIN THE TAILWATERS OF
RICHARD B. RUSSELL DAM

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Introduction

Comparisons of larval fish densities among habitats ("Spatial and Temporal Patterns of Ichithyoplankton Abundance" by Van Den Avyle, this report) revealed that densities were highest in tributaries (Stations 4, 5, 6, and 11) of JST, intermediate in the main lake (Stations 7, 8, 9, and 10), and lowest in the tailrace (Stations 1, 2, and 3). In this presentation, spatial variations within the tailrace are given in more detail to describe how each station contributes to the reproductive potential of the tailwater area. Diel variations, as they relate to generation cycles, are also presented to characterize effects of flushing on the distribution of larval fish in the tailrace.

Methods

Spatial pattern

The spatial variation in ichthyoplankton abundance below RBR Dam was determined by sampling: (a) RBR Forebay (Station 0) in 1987 only; (b) the tailrace between the buoy line and dam face (Station 1); (c) the tailrace between Buoys 147 and 148 (Station 2); (d) the tailrace near Buoy 140 (Station 3), and (e) Russell Creek above the Mt. Pleasant boat ramp (Station 4). Collection sites were visited biweekly at night from 23 February to 3 July 1987 and from 22 February to 13 July 1988.

Four samples were collected at each station using a conical (0.2 m^2) net of 0.505-mm nitex mesh. The net was dropped to a depth of 4 m and then towed for 2-1/2-min at each of the following depths: 4, 3, 2, and 1 m in a stepped oblique manner. Towing speed (1 m/sec) and duration (10 min) were designed to achieve a target volume of approximately 100 m^3.

The contents of each sample were washed into a 500-ml jar and preserved

in 5-percent formalin. In the lab, each specimen was identified to the lowest possible taxon and assigned to one of the following categories: (a) egg, (b) larva, or (c) juvenile. Data presented in this section do not include eggs and juveniles because few were collected.

Diel pattern

To investigate the possible effects of generation on the distribution of larval fishes in the tailrace, diel studies were conducted in April, May, and June of 1988. Collections were made over two continuous 24-hr periods; the first was during periods of generation and the second was not. Sampling sites included Station 2 and Station 2B, located immediately across from Station 2 along the South Carolina shoreline. Both stations were sampled twice during the day and twice at night during each 24-hr period. Methods of collection were similar to those used to survey larval fishes at Stations 0-4.

Results and Discussion

Spatial pattern

Abundance was very low in both the RBR Forebay (Station 0) and the tailrace immediately below the dam (Station 1). In fact, only eight larvae were collected at Station 1 in 1988. Mean densities of the major taxa were consistently lowest in Station 1, where values exceeded 0.1/100 m^3 on only one occasion (Table 11). Catches at Station 1 were not greatly influenced by larvae entering JST from the RBR Forebay, and Station 0 was omitted from the survey in 1988.

Table 11

Mean Densities (number/100 m^3) of Ichthyoplankton at Five Stations Below RBR Dam in 1987 and 1988

	1987 Station					1988 Station			
Species*	0	1	2	3	4	1	2	3	4
Clupeids	1.8	1.8	2.3	37.7	62.1	0.1	17.5	34.2	51.3
Crappies	0.0	0.1	1.2	3.7	13.5	0.0	0.2	2.4	3.6
Lepomis spp.	0.7	0.1	1.0	2.1	4.4	0.0	0.7	0.6	1.7
Yellow perch	0.0	0.1	0.3	1.0	8.9	0.1	0.7	0.2	1.5

* Densities of larval white bass, shiners, common carp, darters, and black basses never exceeded 0.2/100 m^3.

Abundance at tailrace stations increased with increased distance below the dam and apparently was affected by flow. In 1987, 646 larvae were collected at Station 2, and 1932 larvae were collected at Station 3. This threefold difference in abundance between stations in 1987 decreased to a twofold difference during the drought of 1988, when 920 and 1,783 larvae were collected at Stations 2 and 3, respectively. Mean densities of all major taxa were higher at Station 3 than at Station 2 in 1987, but in 1988 mean densities of sunfish and yellow perch were higher at Station 2 than at Station 3 (Table 11).

Larval fish densities were greatest at Russell Creek, the only tributary station near the tailrace. Mean densities for major taxa were highest at Station 4 in both 1987 and 1988 (Table 11). Differences were not as great in the drought year of 1988.

The relative importance of the three tailrace stations as spawning habitat for clupeids was further clarified by evaluating temporal trends in abundance (Figure 81). At no time were more than a few clupeid larvae collected at Station 1. At Stations 2 and 3, densities were similar until early June 1987 and late June 1988 (Figure 81), when clupeid reproduction apparently ceased as evidenced by the decreased numbers of young larvae in samples. Following those dates, numbers increased at Station 3 due primarily to the appearance of large non-planktonic clupeid larvae and decreased at Station 2 where larger clupeids were absent.

Of the tailrace stations (1, 2, and 3), Station 3 had the greatest abundance of crappie (Figure 82) in both years, whereas the abundance of yellow perch and sunfishes was greatest at Station 3 in 1987 but at Station 2 in 1988 (see Figures 83 and 84). In general, the spawning seasons of the three taxa were more extended at Station 3 than at Station 2. Abundance was consistently lowest at Station 1.

Diel pattern

Initial diel studies conducted on 15-17 April 1988 revealed that densities of yellow perch larvae were highest at both stations on the night (April 16 and 17) following a prolonged period of no generation. On April 15, generation occurred between the hours of 0700 and 1200 and 1800 and 2300 (Figure 85). Yellow perch was the only major taxon collected. At Station 2B, where currents were the strongest, ichthyoplankton densities were always low during or immediately after generation.

The second diel study performed on 20-22 May 1988 also showed that

The second diel study performed on 20-22 May 1988 also showed that ichthyoplankton densities were lowest at Station 2B during generation. In addition, more clupeid larvae were collected at Stations 2 and 2B during the second 24-hr period with no generation than during the first 24-hr period with generation. Generation occurred only on May 20 between 1400 and 2400 hr (Figure 86). Clupeids were most abundant, but yellow perch and sunfishes also were represented. All sunfishes and most yellow perch were collected during the final night of the study.

The final diel investigation on 10-12 June 1988 also demonstrated that fewer larvae were present at the station with strong currents. Generation was confined to 1500-2000 hr on June 10 (Figure 87). Larvae of Clupeidae and *Lepomis* were present in most samples. Clupeid densities were low at both stations during generation. Numbers increased on the following day and remained high during the night. More clupeid larvae were collected at Station 2 than at 2B, which had stronger currents. Differences between stations were most pronounced for sunfishes, as larval *Lepomis* were consistently more abundant at Station 2 than at Station 2B across all time periods.

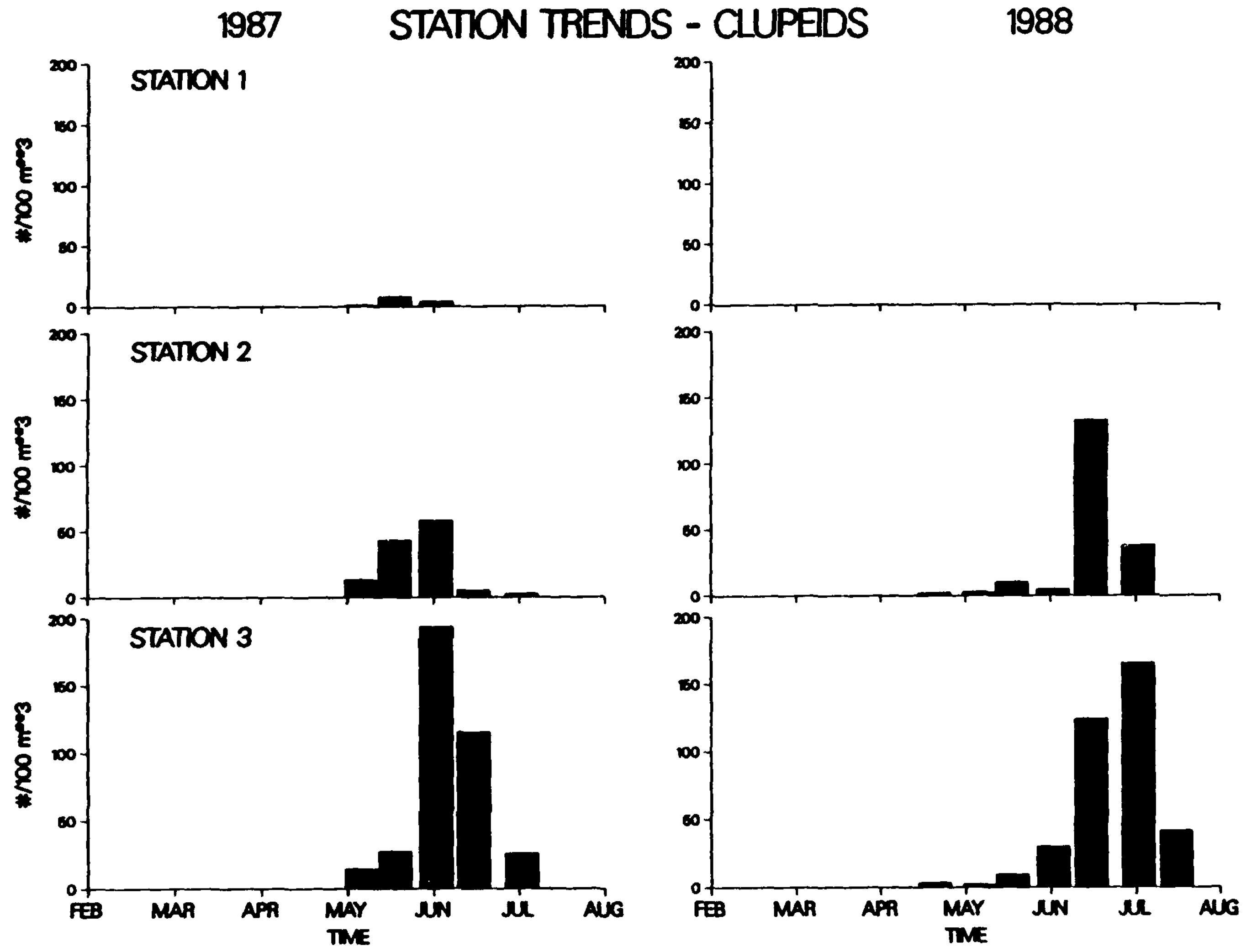

Figure 81. Monthly abundance of larval clupeids by station in RBR tailwater, 1987-88

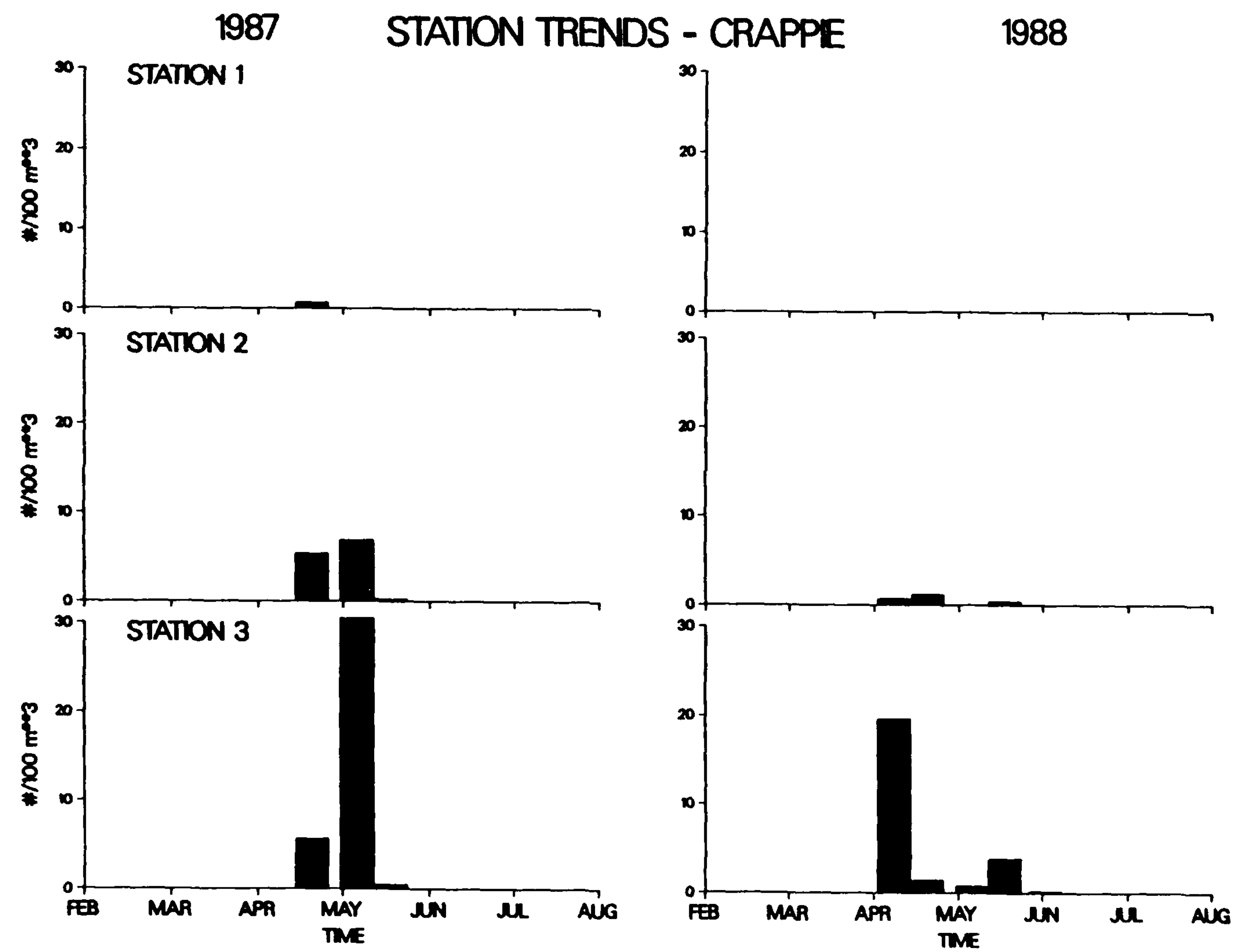

Figure 82. Monthly abundance of larval crappies by station in RBR tailwater, 1987-88

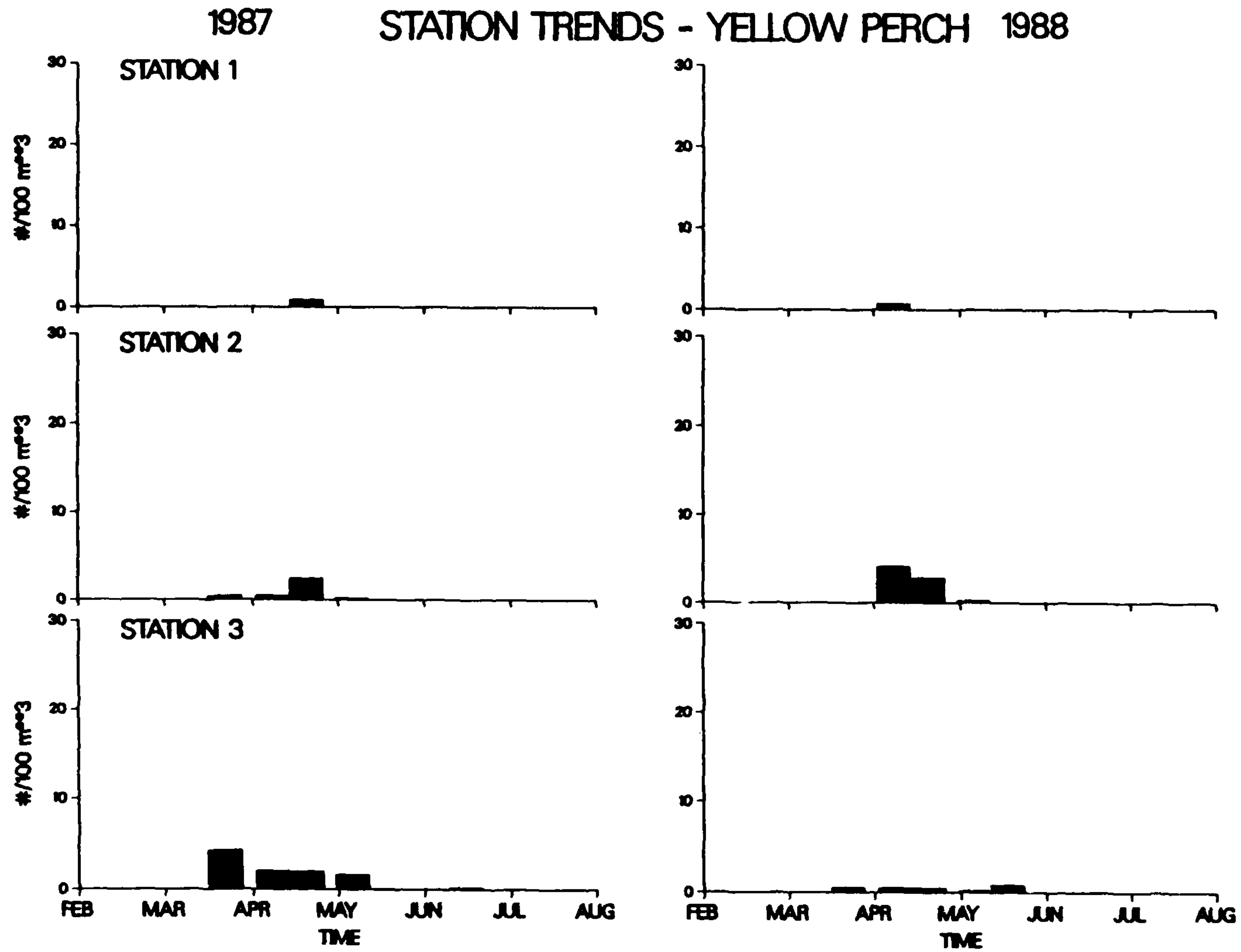

Figure 83. Monthly abundance of larval yellow perch by station in RBR tailwater, 1987-88

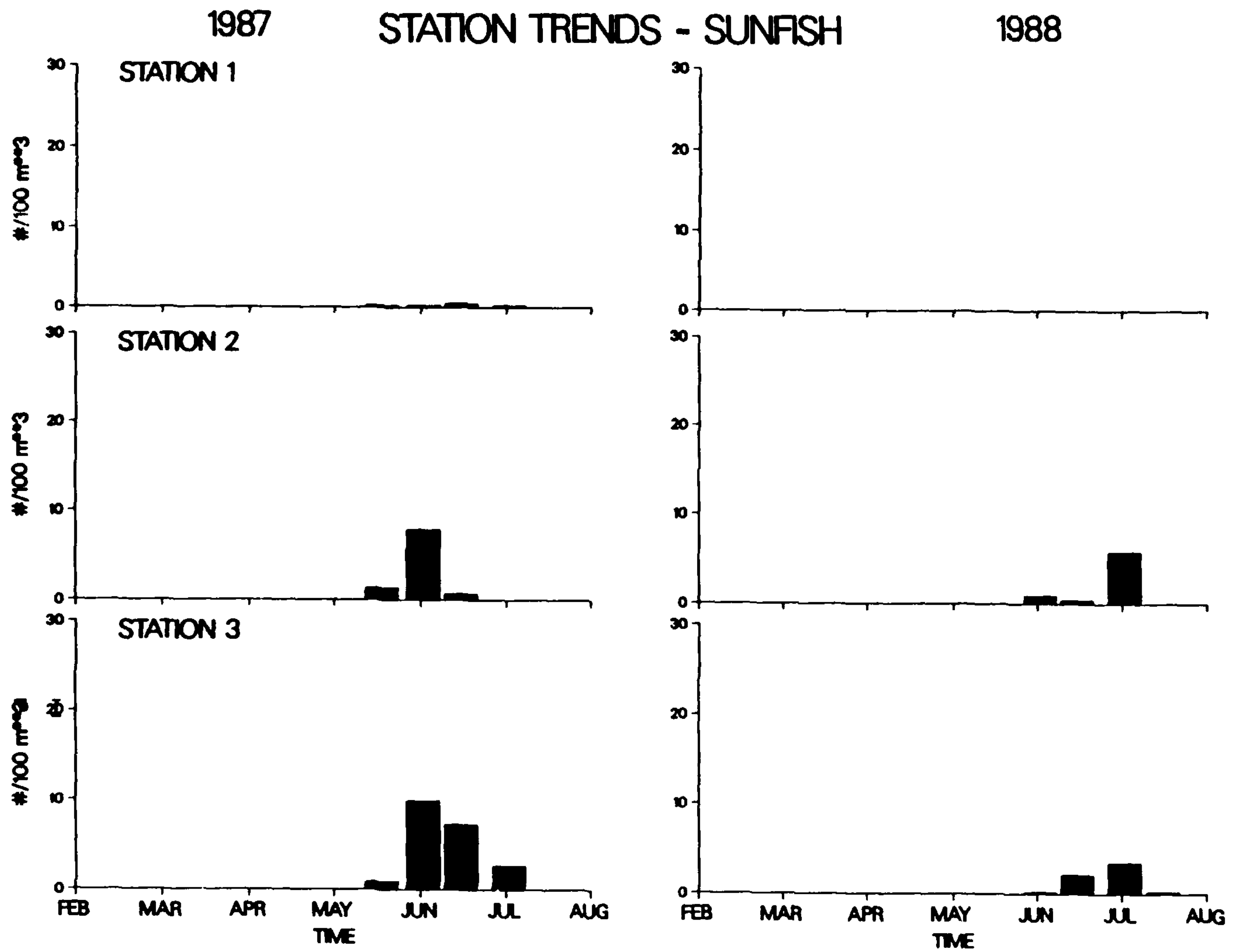

Figure 84. Monthly abundance of larval sunfishes by station in RBR tailwater, 1987-88

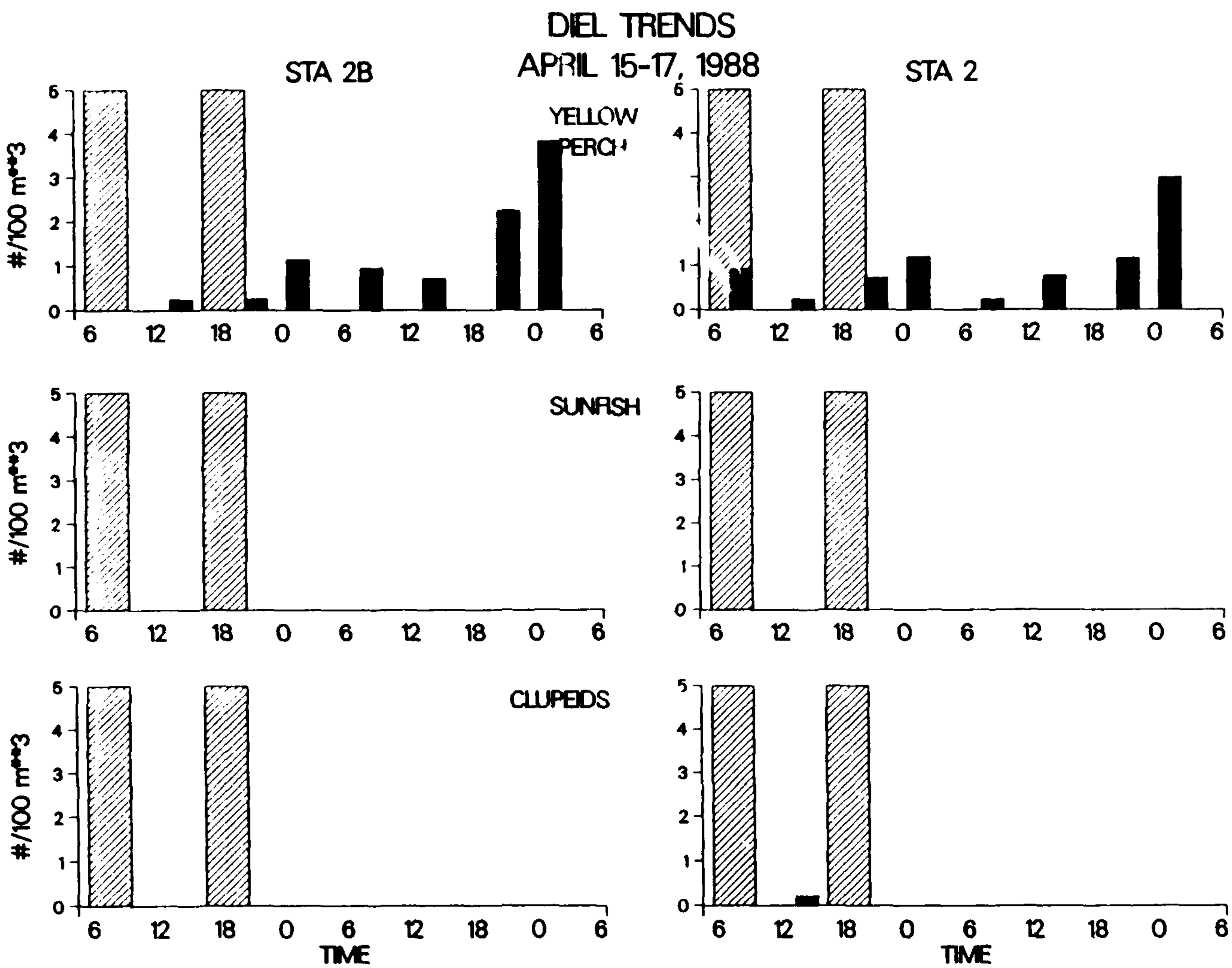

Figure 85. Diel trends in abundance of larval fish (solid bars) at two stations in RBR tailwater in April 1988. Periods of generation are indicated by bars with diagonal shading

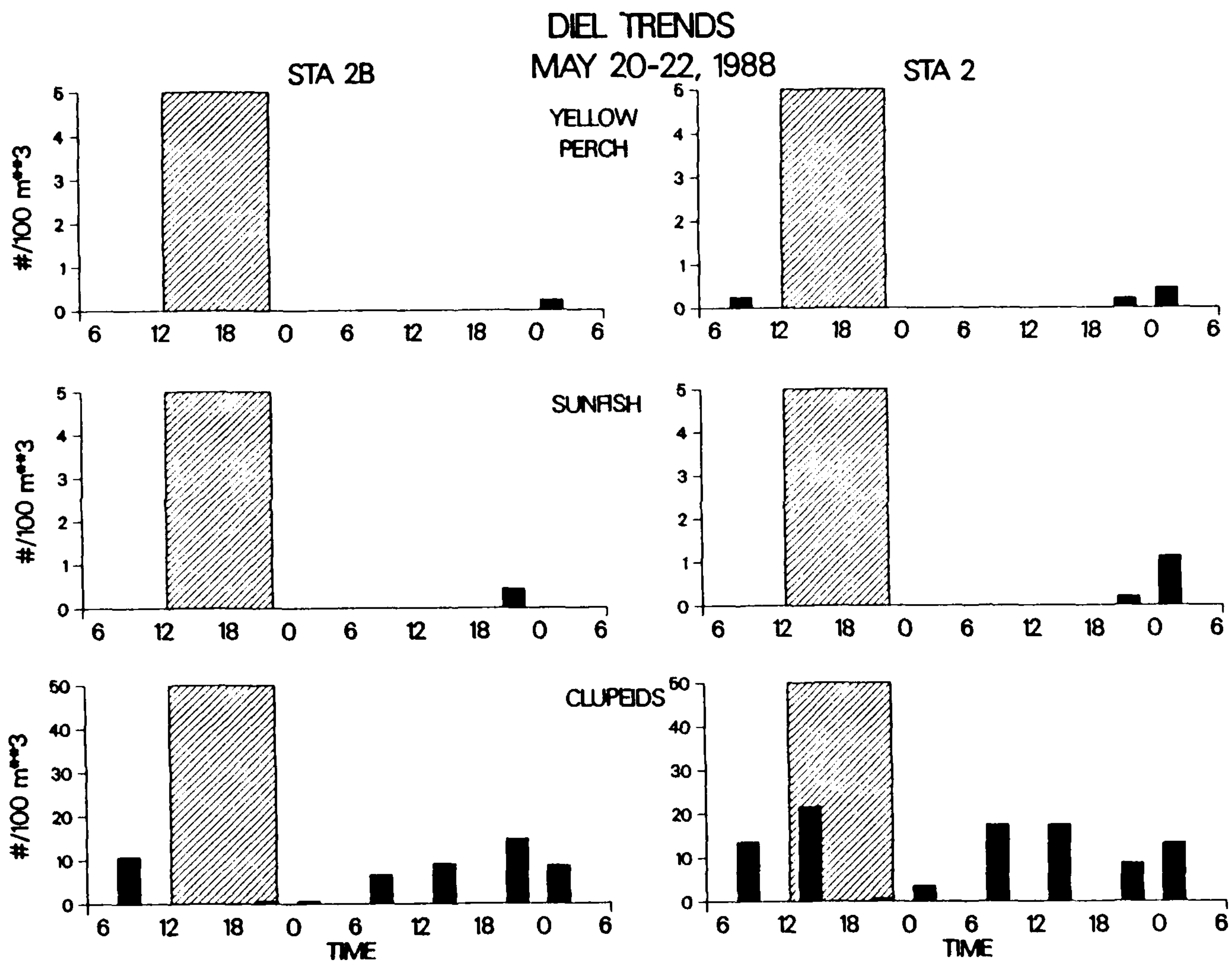

Figure 86. Diel trends in abundance of larval fish (solid bars) at two stations in RBR tailwater in May 1988. Periods of generation are indicated by bars with diagonal shading

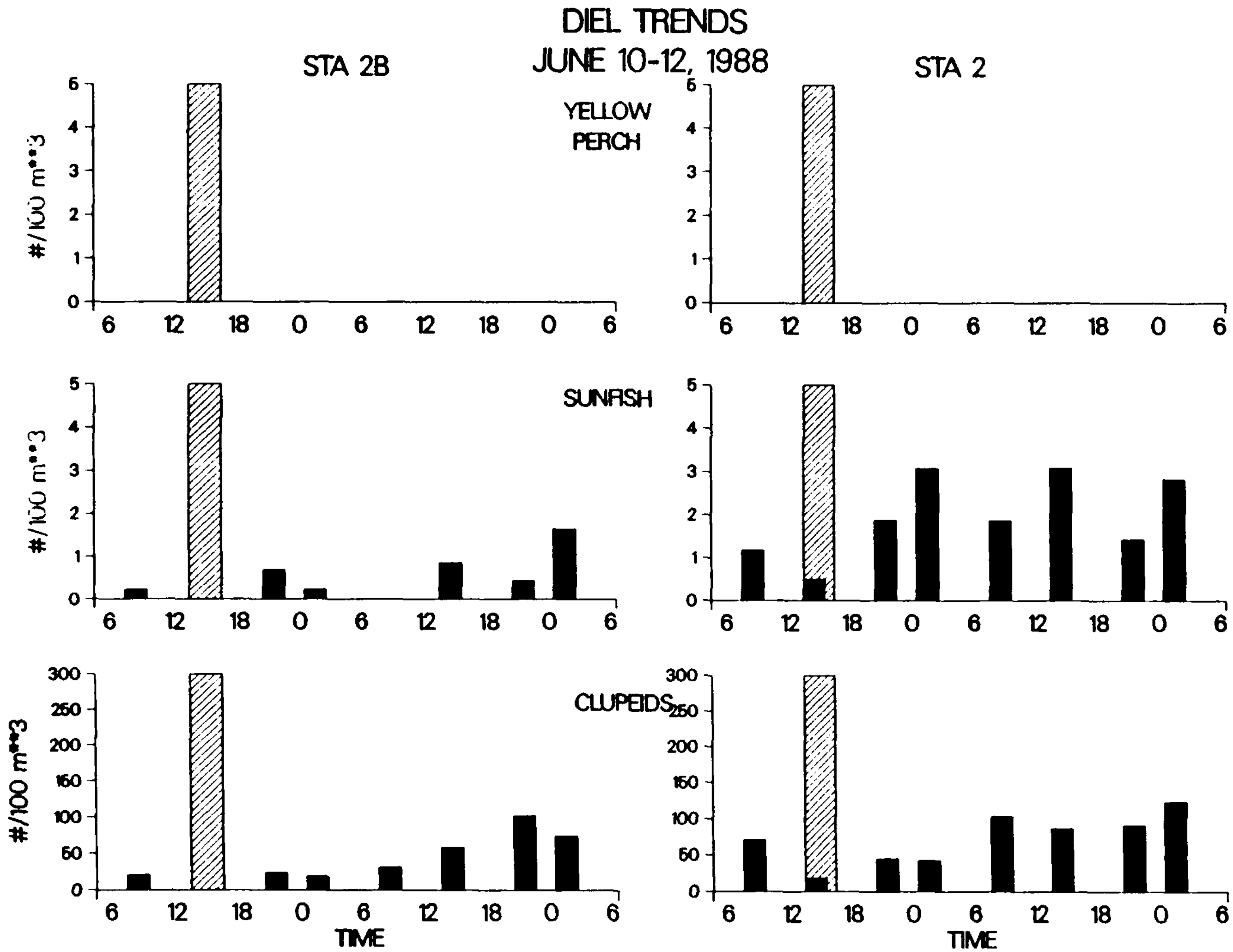

Figure 87. Diel trends in abundance of larval fish (solid bars) at two stations in RBR tailwater in June 1988. Periods of generation are indicated by bars with diagonal shading

FISH DISTRIBUTION IN THE TAILWATERS OF RICHARD B. RUSSELL DAM AS DETERMINED BY RADIO TELEMETRY

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Introduction

In 1987 and 1988, the Georgia Cooperative Fish and Wildlife Unit conducted radio telemetry studies in the tailwater of RBR Dam on JST Lake. The objectives of these studies were to (a) determine the spring and summer distribution of striped bass, white bass × striped bass hybrids (hybrid bass), and sauger in the tailwater, and (b) discern the effects of operations at RBR Dam on the distribution of these fishes.

Methods

Study specimens were captured in gill nets set primarily inside the buoy line at RBR Dam and in the first embayment. Radio transmitters were implanted in the body cavity when fish were in good condition and water temperatures and attendant risk of infection were low. They were attached externally on the lateral-dorsal surface when fish were in poor condition or water temperatures and associated risk of postsurgery infection and death were high. Following surgery, fish were released at the point of capture.

Routine tracking efforts were conducted twice per week in the tailwater and once per week in the Broad River and down-lake areas of JST. Fish were tracked by boat (1987 and 1988) or by air (1987) using a scanning receiver and a hand-held antenna.

The effects of RBR operations on fish distributions in the tailwater were assessed with a series of monthly diel tracking studies. These studies consisted of a fish-tracking effort every 4 to 6 hr over a 24- or 48-hr period and focused primarily on fish located within 4 km of the project.

Results

Seasonal distribution in RBR tailwater

Hybrid bass. In 1987, a total of 39 hybrids were tagged, and 53 radio contacts (also referred to as "sightings") were made in spring and 15 in summer. In 1988, however, only 17 fish were tagged, and efforts were concentrated on tracking, which resulted in almost 100 radio contacts over spring and summer (Table 12).

Table 12

Numbers of Hybrid Bass, Striped Bass, and Sauger Tagged and Subsequently Located by Radio Telemetry in RBR Tailwater

Sample Period	Hybrids Tagged	Hybrids Located	Striped Bass Tagged	Striped Bass Located	Sauger Tagged	Sauger Located
Mar-May 87	18	53	5	5	7	31
Jun-Jul 87	21	15	6	7	3	15
Apr-May 88	8	20	5	7	11	79
Jun-Jul 88	9	42	7	0	1	74
Aug-Sep 88	0	35	0	20	0	46

In spring 1987 and 1988, hybrids were widely distributed and moved extensively throughout the Savannah and Broad River arms of JST (Figure 88). In Figure 88 and other telemetry figures, single points may reference the location of one or more sightings. In summer, however, these fish showed limited movement within certain locations along the Savannah arm (Figures 89 and 90). Locations varied with the water level (between years) and with progressive warming of the reservoir in summer.

Striped bass. Catches of striped bass for telemetry were quite low in 1987 and 1988 (Table 12). Only 11 fish were tagged and 12 radio contacts made in spring and summer, 1987. The low number of contacts may be attributed to high mortality rates among striped bass following tagging and movement of study specimens out of the tailwater. A similar situation developed in 1988, although 20 radio contacts were obtained during late summer from two fish that remained in the tailwater.

Although the number of striped bass radio contacts were low in 1987 and

1988, the available data indicate distribution patterns similar to those of hybrid bass (Figures 91-93).

Sauger. Sauger-tagging success was high in 1987 and 1988 (Table 12). During spring and summer in 1987, 10 fish were tagged, and 46 radio contacts were made. Likewise, in 1988, 12 fish were tagged, allowing almost 200 contacts to be recorded. Most of these tagged sauger remained in the tailwater area throughout the spring and summer of both years (Figures 94-96).

Effects of RBR operations

Diel-tracking studies were conducted monthly from April to September 1988. Fish distributions on a diel basis were similar among months (Figures 97-102). Hybrids showed limited movement over the 48-hr period and did not appear to migrate toward or away from the project during generation, although minor shifts in location may have occurred. In addition, only slight changes were detected in sauger distribution on a diel basis, and no apparent change were detected in distribution during generation.

Summary

Hybrid and striped bass moved widely throughout the Savannah and Broad River arms in spring 1987 and 1988. During summer, these fish showed limited movement within restricted areas of the Savannah arm. The locations of these areas changed with water level and water quality as the summer progressed. Sauger remained in the tailwater throughout spring and summer of both years. Telemetry revealed no major upstream or downstream movements of hybrid bass, striped bass, or sauger in response to generation, although localized movements may have occurred.

HYBRID BASS

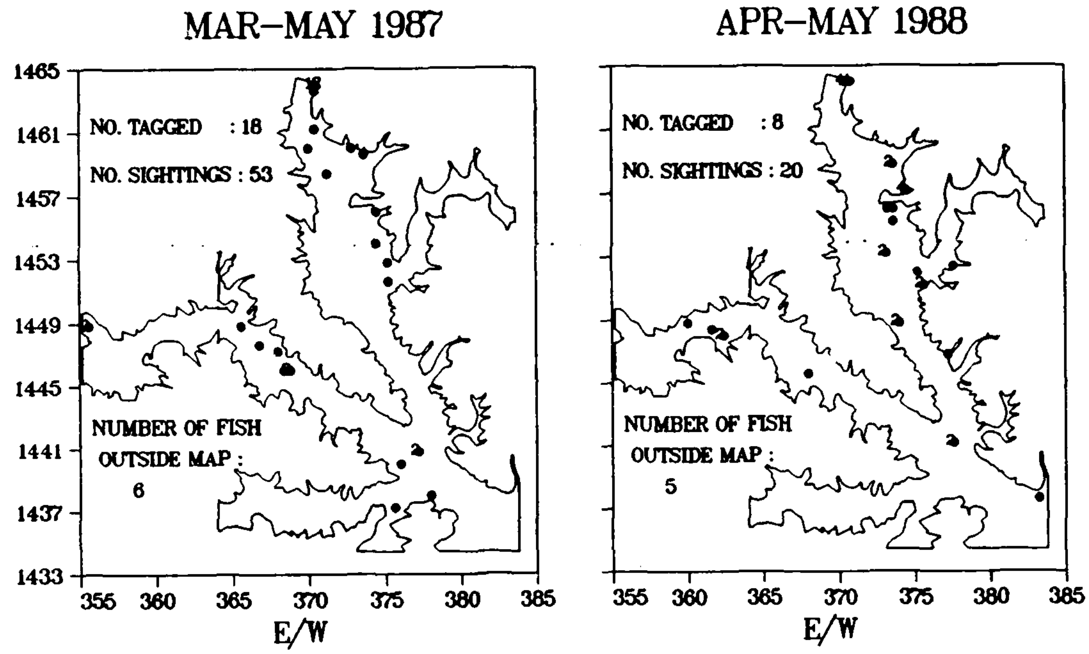

Figure 88. Locations of white bass × striped bass hybrids as revealed by radio telemetry in the upper end of JST Lake in March-May 1987-88

HYBRID BASS

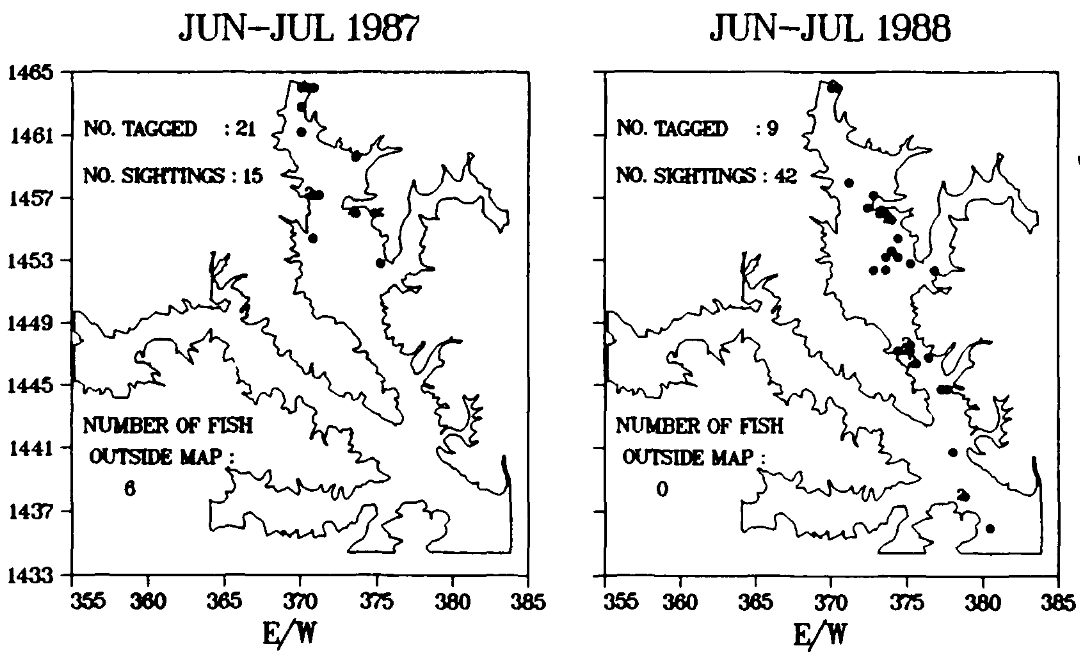

Figure 89. Locations of white bass × striped bass hybrids as revealed by radio telemetry in the upper end of JST Lake June and July 1987-88

HYBRID BASS

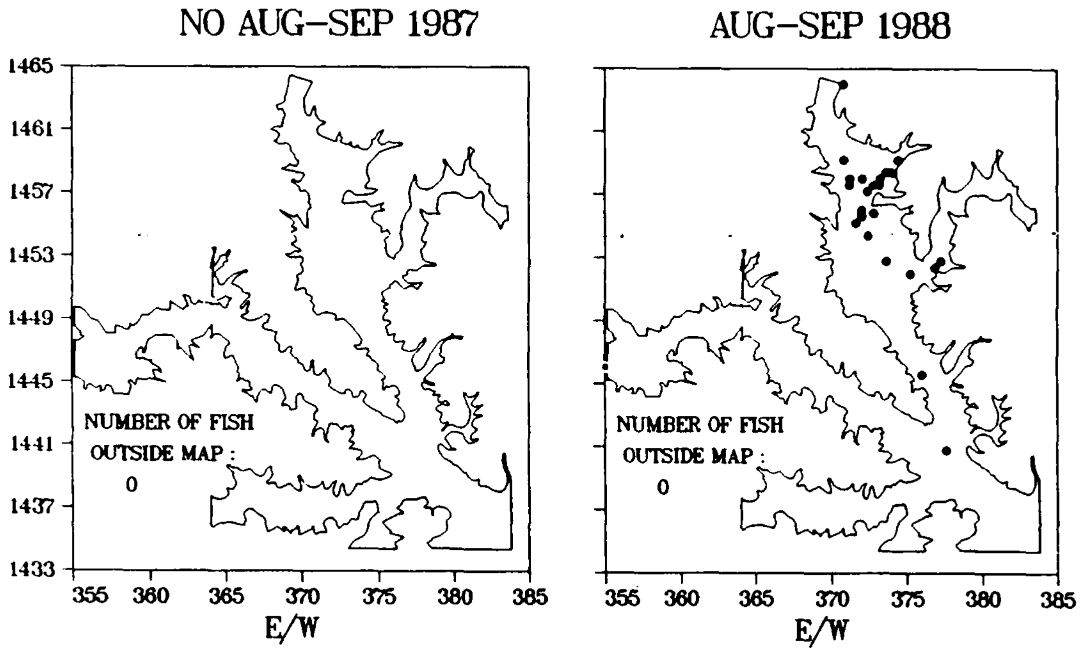

Figure 90. Locations of white bass × striped bass hybrids as revealed by radio telemetry in the upper end of JST Lake in August and September 1987-88

STRIPER

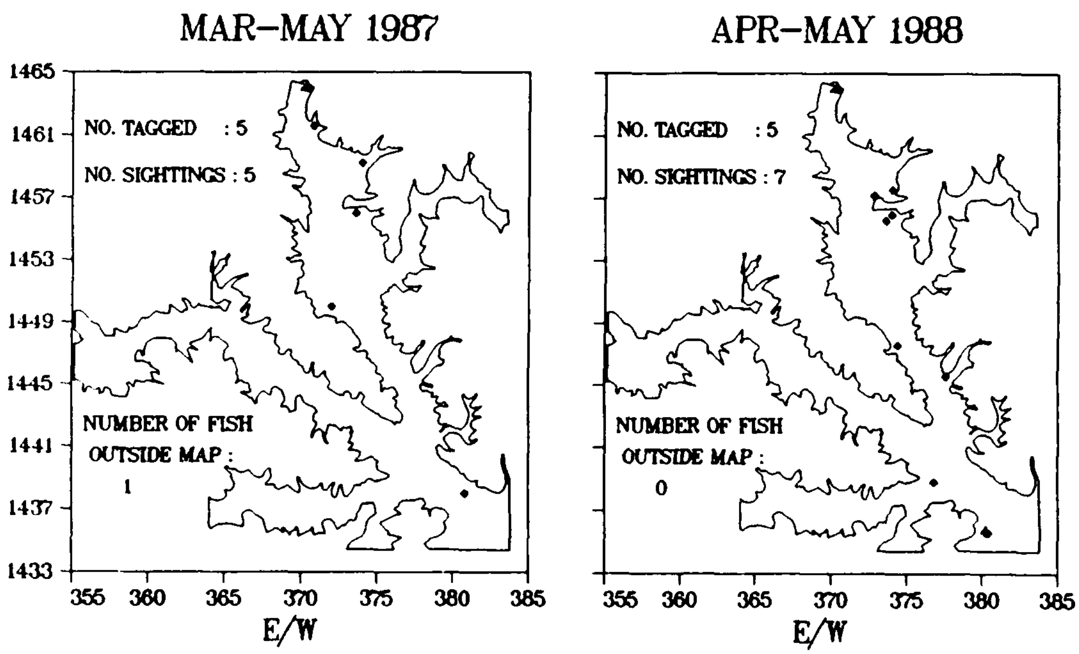

Figure 91. Locations of striped bass as determined by radio telemetry in the upper end of JST Lake in March-May 1987-88

STRIPER

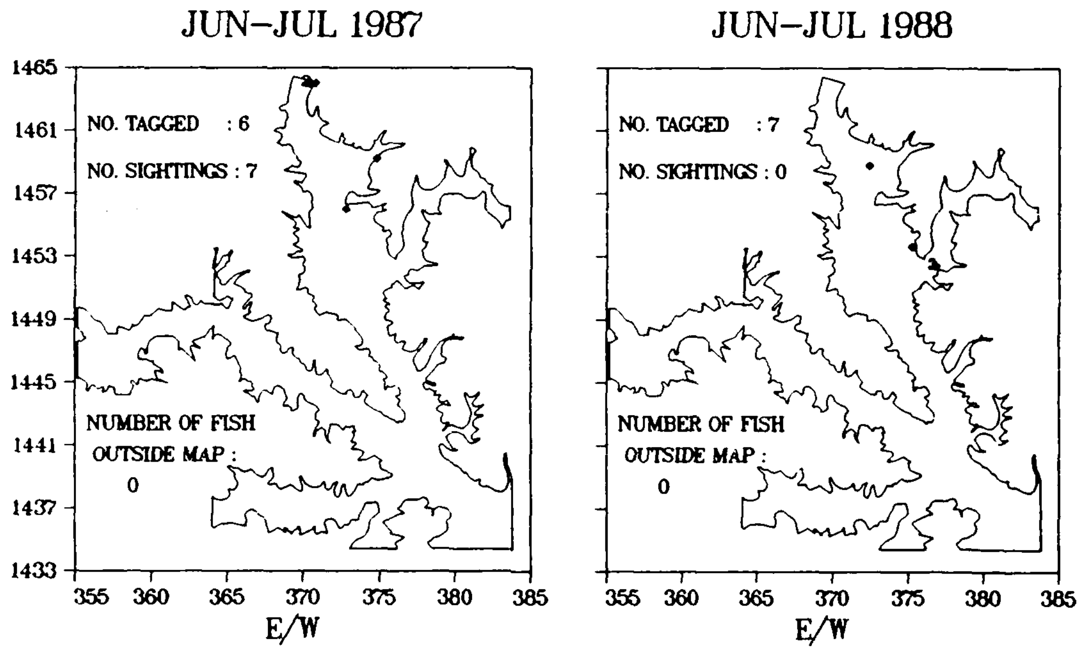

Figure 92. Locations of striped bass as determined by radio telemetry in the upper end of JST Lake in June and July 1987-88

STRIPER

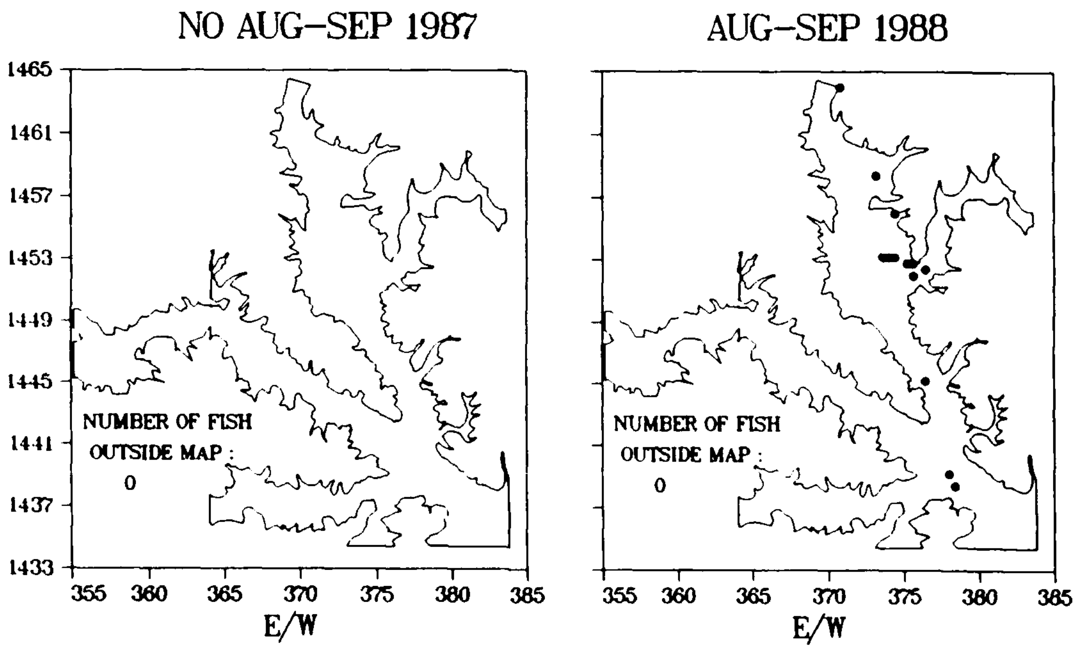

Figure 93. Locations of striped bass as determined by radio telemetry in the upper end of JST Lake in August and September 1987-88

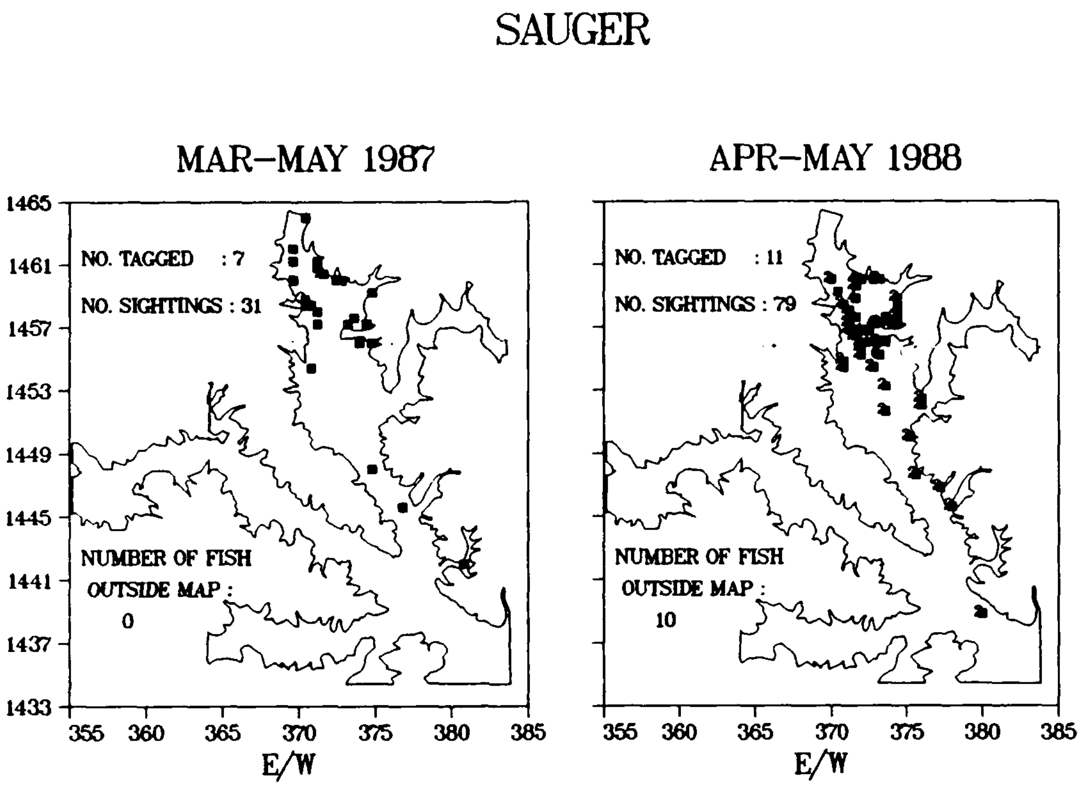

Figure 94. Locations of sauger as determined by radio telemetry in the upper end of JST Lake in March-May 1987-88

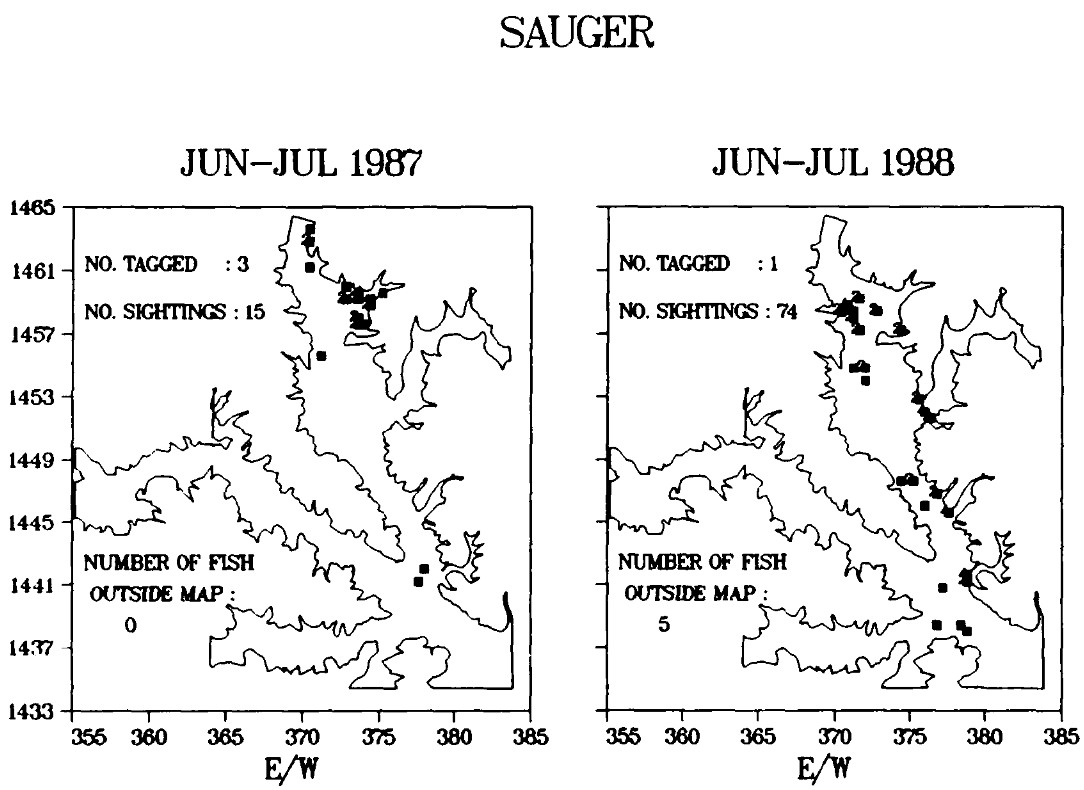

Figure 95. Locations of sauger as determined by radio telemetry in the upper end of JST Lake in June and July 1987-88

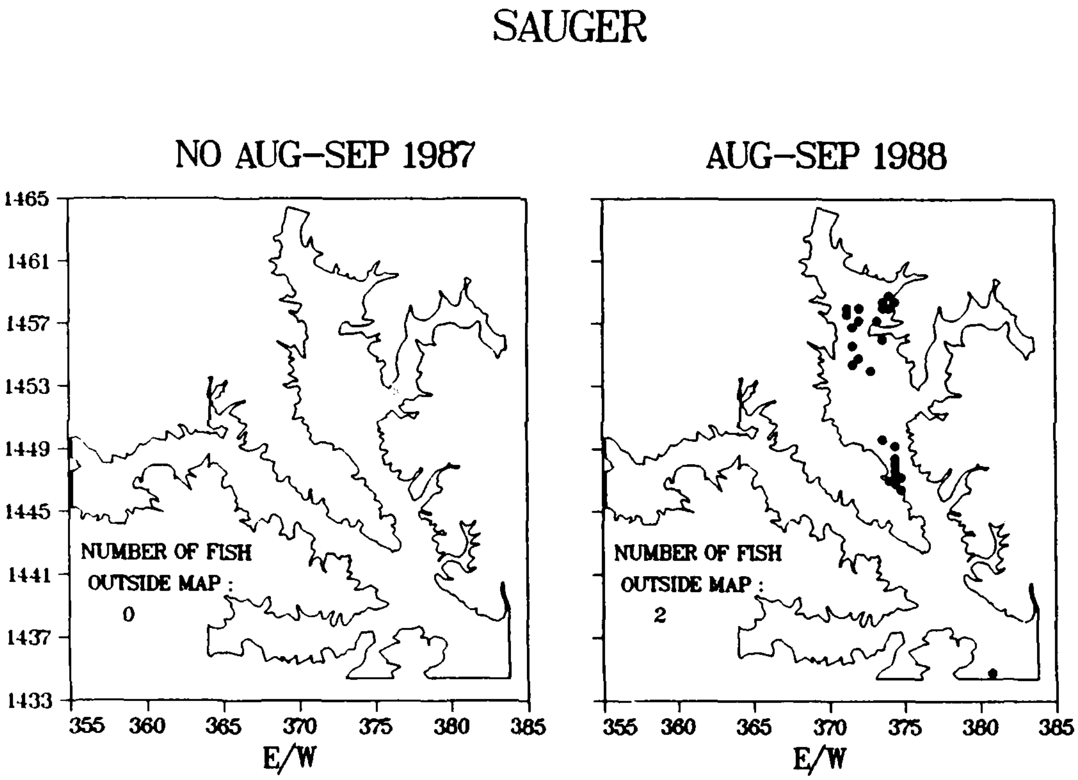

Figure 96. Locations of sauger as determined by radio telemetry in the upper end of JST Lake in August and September 1987-88

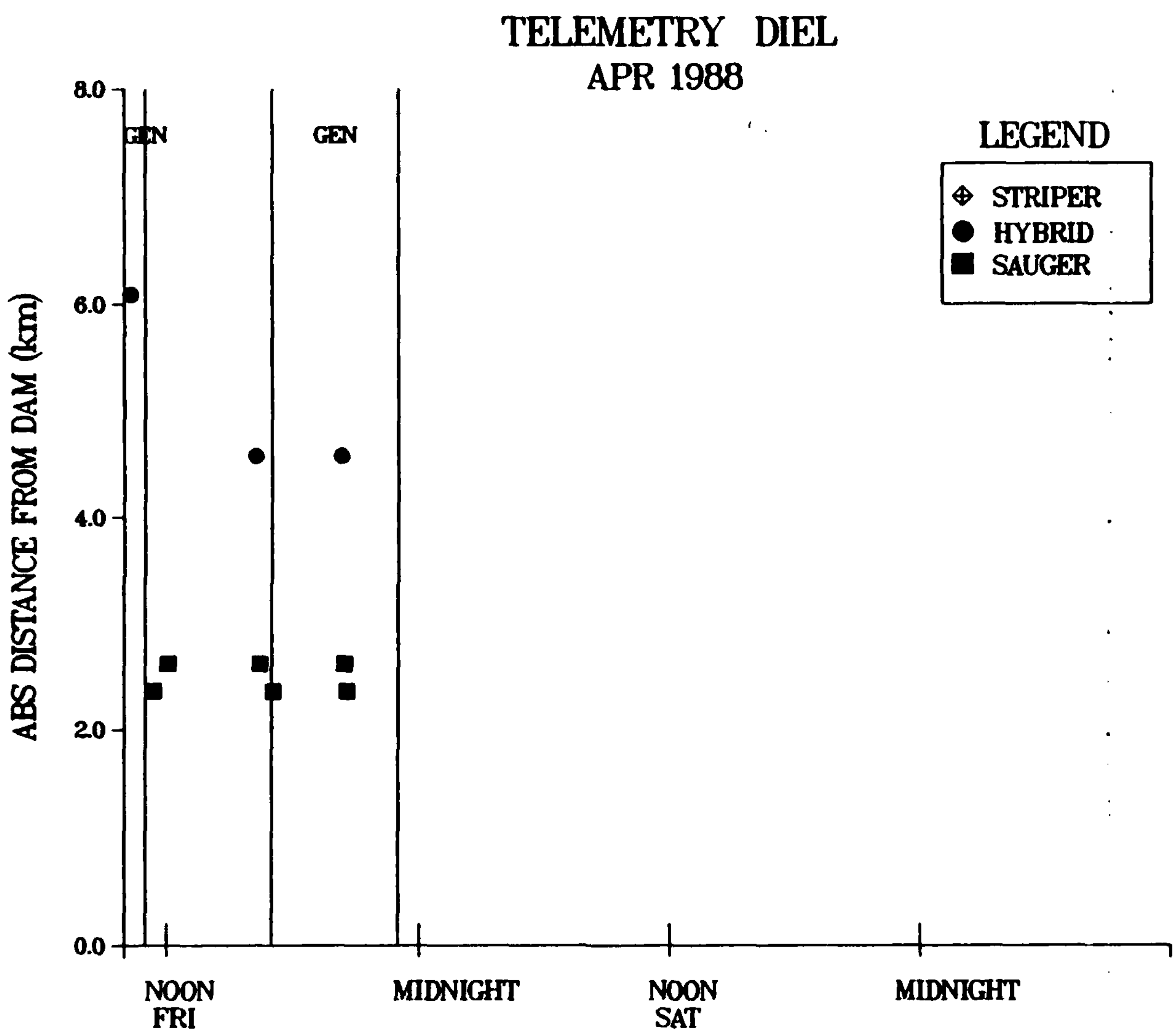

Figure 97. Distances of striped bass, hybrid bass, and sauger below RBR Dam on a diel basis in April 1988

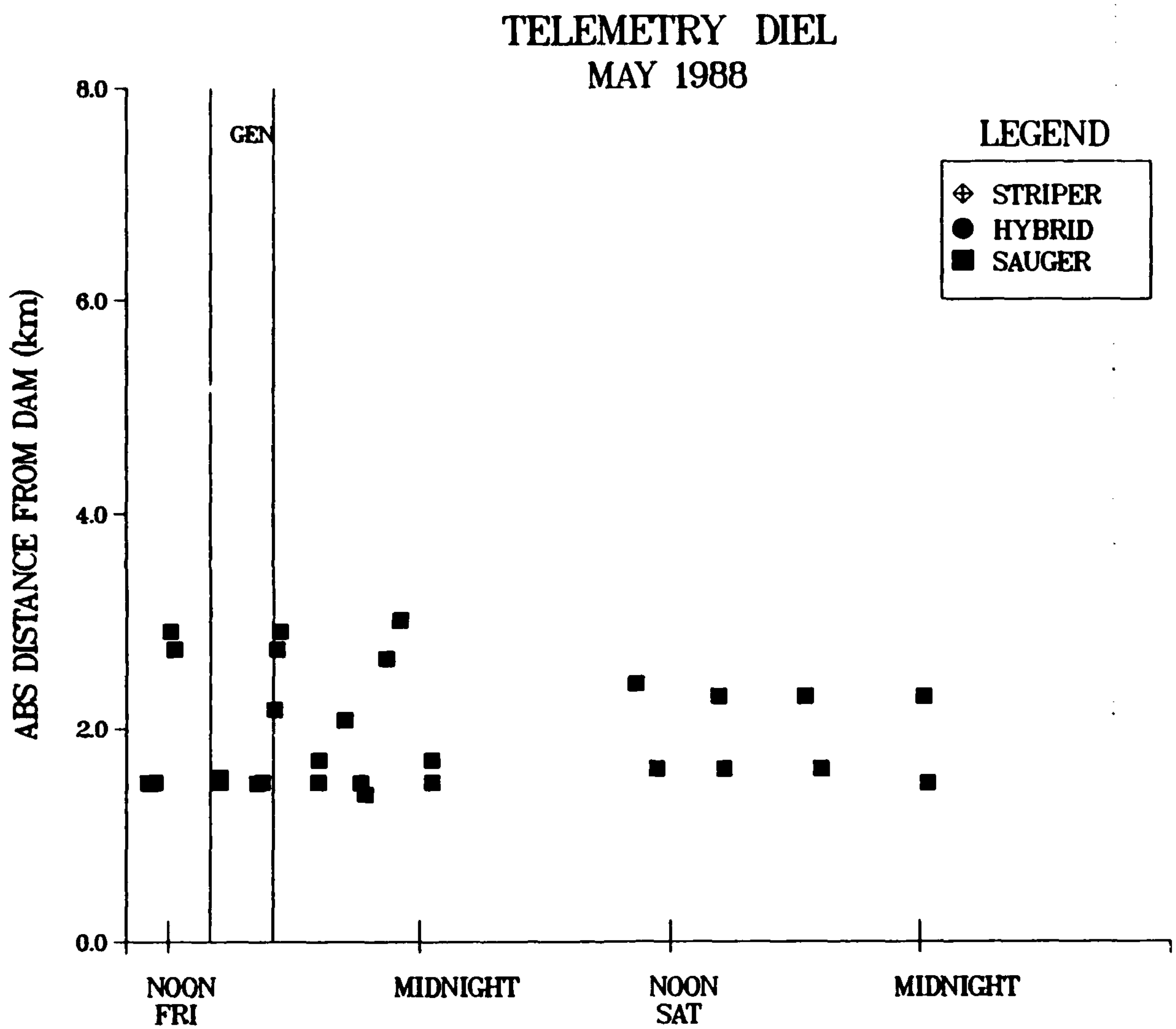

Figure 98. Distances of striped bass, hybrid bass, and sauger below RBR Dam on a diel basis in May 1988

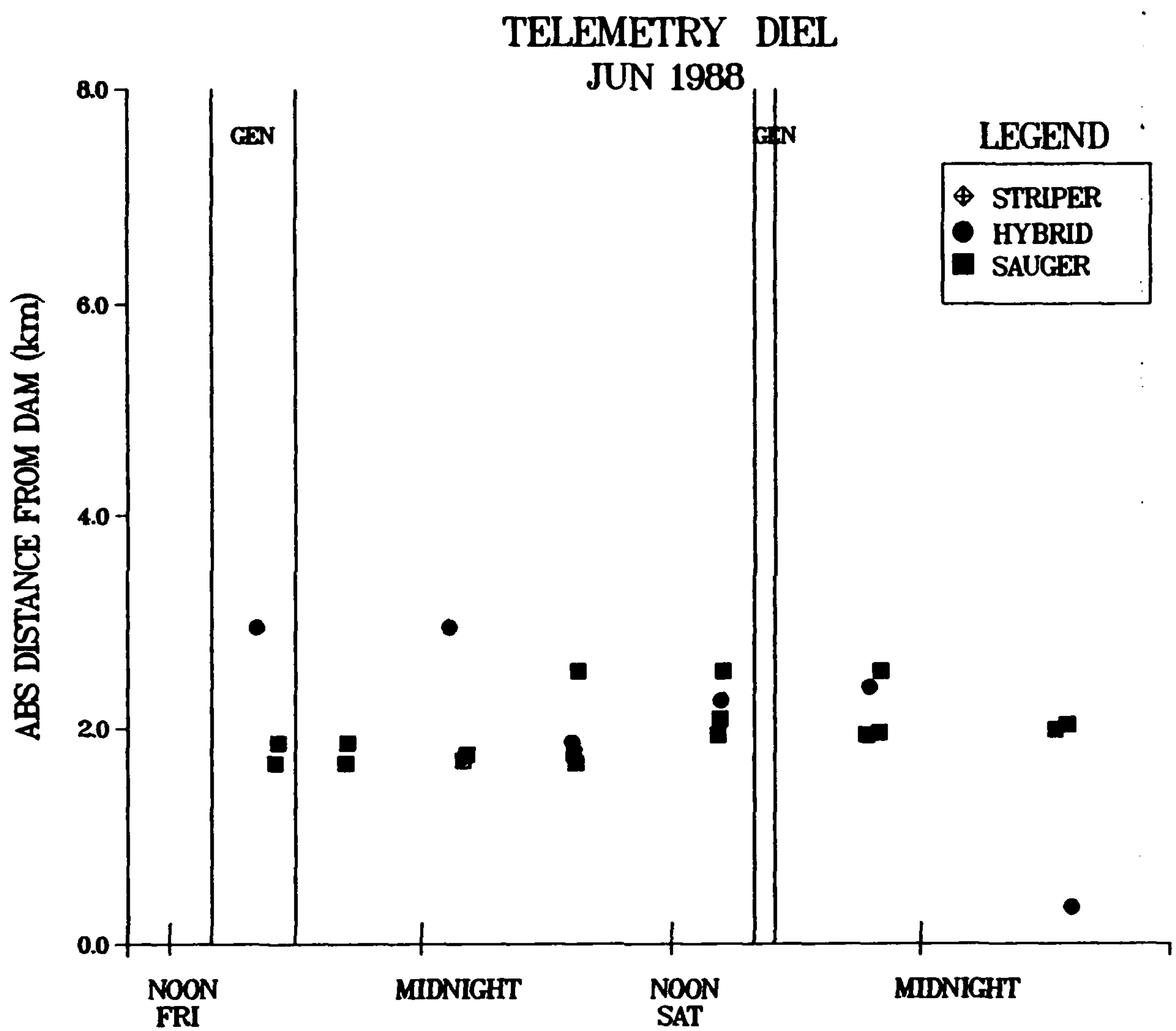

Figure 99. Distances of striped bass, hybrid bass, and sauger below RBR Dam on a diel basis in June 1988

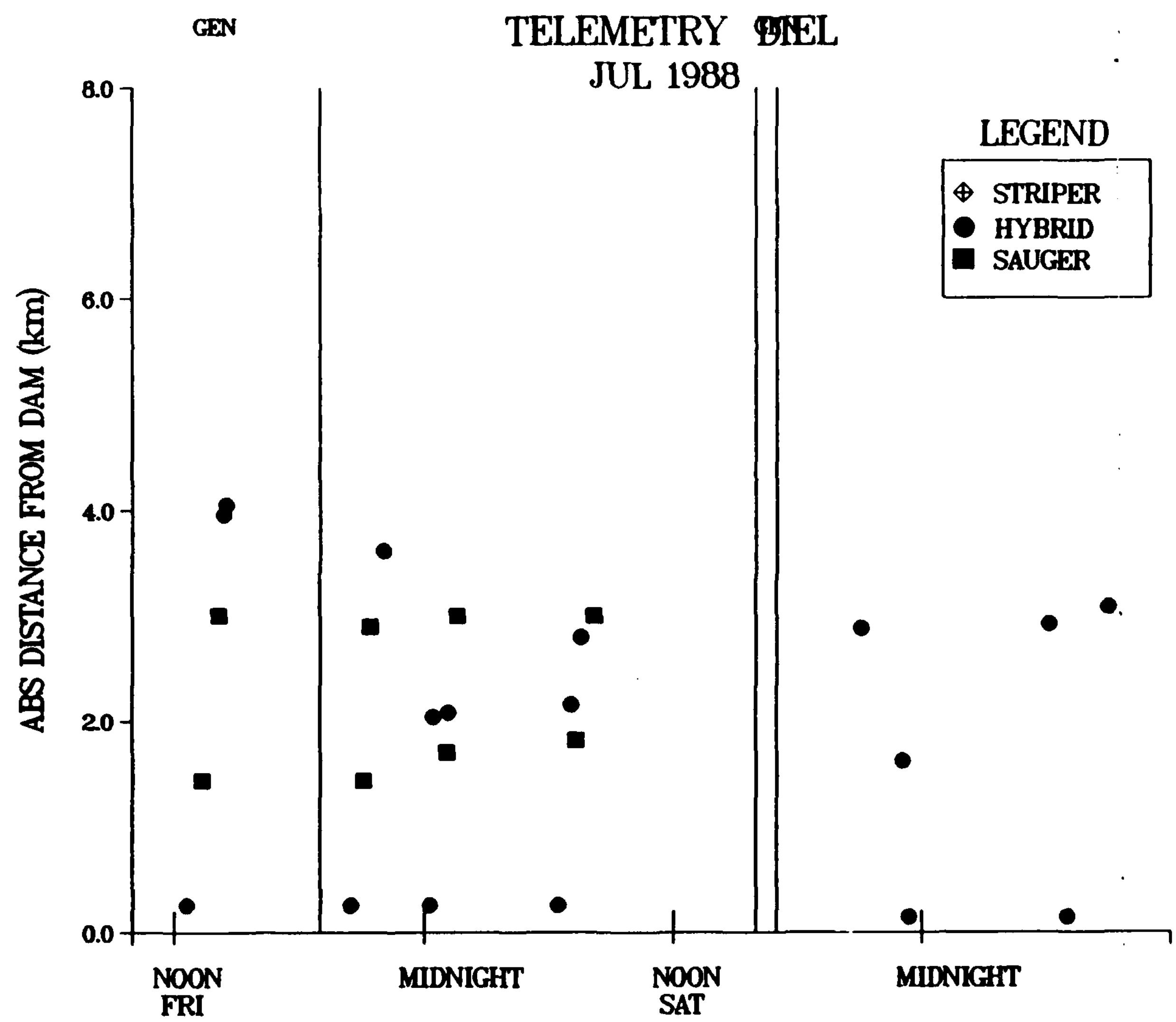

Figure 100. Distances of striped bass, hybrid bass, and sauger below RBR Dam on a diel basis in July 1988

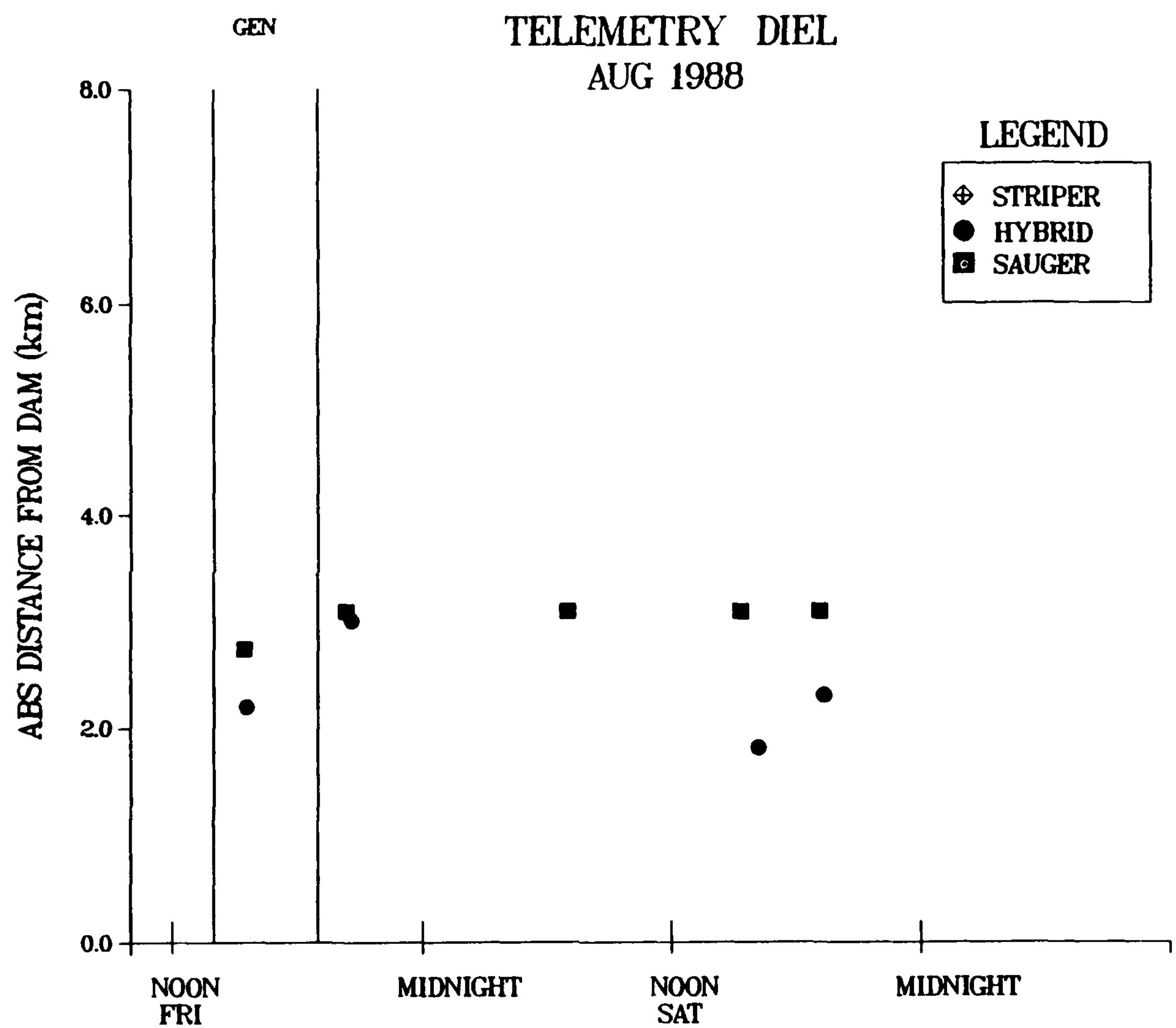

Figure 101. Distances of striped bass, hybrid bass, and sauger below RBR Dam on a diel basis in August 1988

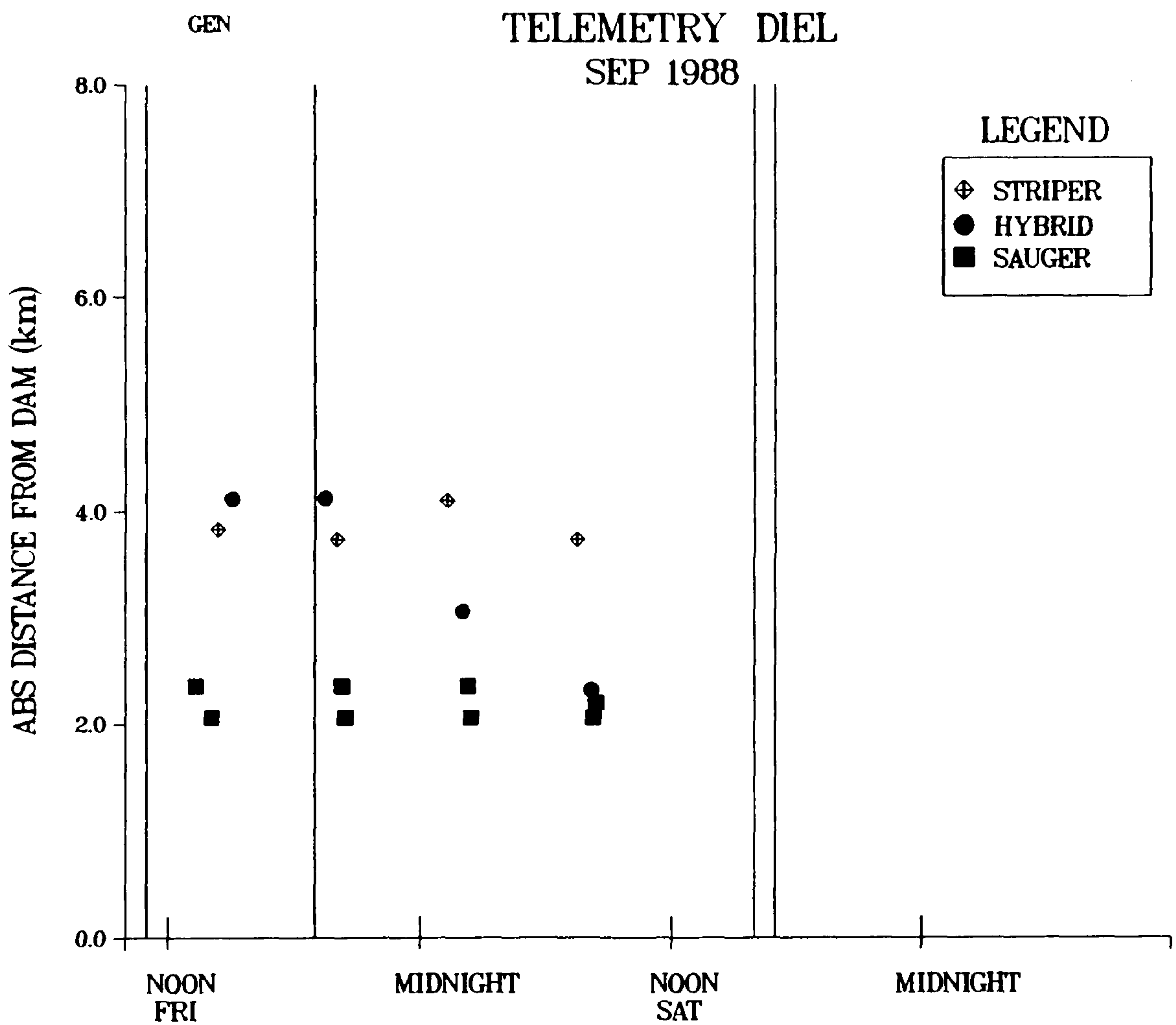

Figure 102. Distances of striped bass, hybrid bass, and sauger below RBR Dam on a diel basis in September 1988

COMPARISONS OF RICHARD B. RUSSELL WITH OTHER PROJECTS

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Introduction

Data were obtained on fisheries at two other pumped-storage projects to provide a framework in which to evaluate data from RBR. The magnitude of average relative biomass by hydroacoustics, for example, was more meaningful after it was compared with that from a project that has had serious fish entrainment problems (Harry S. Truman, Missouri) and with another project that has no problems (Wallace Dam, Georgia). Surveys had already been conducted at the Harry S. Truman Project in Missouri for other purposes (USAED, Kansas City), and data from that study could be used to represent a project that had known fish entrainment problems. Wallace Dam is a Georgia Power Company pumped-storage project within 60 miles of RBR Dam. Although hydroacoustic surveys had not been conducted there previously, its proximity to the RBR Project made it convenient to survey. Wallace Dam had been operating in pumped-storage mode for nearly 10 years with no apparent fish entrainment problems. Comparisons made in this study were not intended to provide comprehensive evaluations of tailwater fisheries below Harry S. Truman or Wallace Dams.

Methods

Surveys were conducted in the Harry S. Truman Dam tailrace by the USAED, Kansas City, using BioSonics, Inc., equipment similar to that used at the RBR Project. Tailrace sampling was conducted in March, April, July, and October 1987 and in February, April, and August 1988. Surveys along transects within 100 m of the dam were conducted only in July and October 1987 and in February and August 1988. All surveys were conducted during daylight hours except in August 1988 when night surveys were also performed. Copies of taped data were forwarded from WES to BioSonics, Inc., for processing. The same equipment and

technicians that processed data for the RBR Project were used to process tapes for target strength and biomass data.

Truman tailrace was sampled at four transects perpendicular to the main channel and parallel to the dam, four perpendicular transects spaced farther apart and farther downstream from the dam, and three transects parallel to the main channel and extending from the farthest perpendicular transect to the dam (Figure 103). Transects 1 and 3 covered the powerhouse portion of the tailrace, and Transect 2 covered only the spillway portion; the remaining parallel transects spanned the entire width of the tailrace. Transects were not necessarily sampled in the same direction each time, and some were run more than once during a survey.

Comparisons of relative biomass among projects required correction for calibration differences in Truman and RBR equipment. Truman biomass data were multiplied by a correction factor for the difference between machine constants before the two data sets were compared. Target strength data were already corrected by the dual beam processor, which included specific calibration parameters.

Surveys of the Wallace Dam tailrace were conducted by WES personnel on days when generation occurred, using the same boat and acoustic equipment as at RBR Dam. The tailrace was sampled twice during the day in April, once at night and once during the day in May, once at night in July, and once at night and once during the day in September. Seven transects were surveyed in the tailrace within 200 m of Wallace Dam with the same spacing as in RBR tailrace (Figure 104); the first transect was replicated 3 times each survey period (except in July) to have sufficient numbers of targets for relative size analysis. Data were processed by BioSonics, Inc., in the same manner as for RBR. Each of the Transect 1 replicates was weighted by a factor of one-third when computing a mean value for all transects. The RBR and Wallace tailraces are approximately the same width, but Truman tailrace is about 50 percent narrower than the others (Figure 105).

Results

Relative biomass

Means of Transects 1-5 at RBR and Truman tailraces were compared (Figure 106) because these transects covered approximately the same distance below each dam. Average biomass at Truman was higher than that from

below each dam. Average biomass at Truman was higher than that from corresponding samples below RBR Dam, even though only five samples at Truman included the area close to the dam and all but one was collected during the day. Below RBR, biomass usually was highest at transects near the dam at night.

Mean biomass was higher at Transects 6-11 in Truman tailwater than at Transects 13-23 in RBR tailwater (Figure 107), although the tailwater at RBR was much larger than that at Truman (Figure 105).

Mean biomass estimates for Wallace tailrace Transects 1-5 were significantly lower than comparable estimates from RBR tailrace Transects 1-12 but were in the same range as means for RBR tailwater, Transects 13-23, although somewhat higher in April and May (Figure 108). Transects 6 and 7 at Wallace Dam were not included in the comparison because they were spaced at different intervals and were beyond the tailrace and tailwater area of concern.

The mean depth of fish biomass was greatest below Wallace Dam, intermediate below Truman Dam, and lowest below RBR Dam (Table 13). Mean depth of

Table 13

Comparison of Mean Depths (m) of Fish Biomass at RBR, Truman, and Wallace Tailraces

Project	Mean Depth (m)	
	Day	Night
Russell Dam 1986-88	3.2	2.8
Truman Dam 1987-88	4.0	3.8
Wallace Dam 1988	7.3	6.1

biomass during the day and at night was computed for the three projects based only on transects closest to the dam (1 and 2 for RBR and Wallace and 1-4 for Truman). Mean depth was weighted by the biomass of fish in each 1-m depth stratum. Sampling effort was considerably greater at RBR than at either of the other projects, and surveys did not sample equal areas of about the same depth.

Target strength

Target strength distributions for fish in the Truman tailrace, grouped by survey date and time (Figure 109), had larger mean lengths (26.9 to 105.7 cm) than those from the RBR tailrace (4.3 to 19.7 cm). Mean depths of

(1.7 to 3.1 m). However, total numbers of targets were considerably lower at Truman than at RBR.

Target strength distributions of fishes in Wallace Dam tailrace (Figure 110) had mean lengths that were intermediate between those at RBR and those at Truman (Table 14). Means ranged from 11.4 to 38.1 cm. Depths of targets at Wallace Dam ranged from 2.8 to 7.0 m, which was deeper than at Truman or RBR.

Table 14

Comparison of Mean Lengths (cm) of Fish at RBR, Truman, and Wallace Tailraces Based upon Target Strengths Measured in Hydroacoustic Surveys

Project	Mean Length (cm)	
	Day	Night
Russell Dam 1986-88	8.8	8.8
Truman Dam 1987-88	75.2	106.2
Wallace Dam 1988	25.7	14.2

Water quality effects

Water quality differed greatly at Wallace Dam and Russell Dam during the time acoustic surveys were conducted and may have influenced the species composition and abundance of fish present. Fish biomass was much higher at RBR tailrace than at the Wallace tailrace, where temperatures were warmer, dissolved oxygen levels lower, and turbidity greater than at RBR. Lake Oconee, which is upstream of Wallace Dam and a smaller reservoir than RBR Lake, has greater turbidity and does not stratify thermally, presumably because of pumped-storage operations. Lake Oconee does not have an oxygenation system for improving tailrace dissolved oxygen levels as at RBR. Water quality conditions below Wallace Dam probably do not provide as attractive a habitat as those below RBR Dam for prey or sport fish such as striped and hybrid bass. Blueback herring apparently do not occur in Lake Sinclair (downstream of Wallace Dam) or Lake Oconee.

Water quality conditions and geographical distributions of certain species of fish may also explain why relative biomass was higher in Truman tailrace than in RBR tailrace. The essentially warmwater tailwater below Truman Dam provides good habitat for catfish and common carp, both of which tend to be more abundant in the Midwest than in the Southeastern United States

Truman Dam provides good habitat for catfish and common carp, both of which tend to be more abundant in the Midwest than in the Southeastern United States (Leidy and Jenkins 1977). Target strengths of fish at Truman also were much larger than those at RBR, and sampling with other methods confirmed that many of the large fish at Truman were catfish and common carp.

Draft tube dewatering

Draft tubes at RBR and Truman were dewatered periodically to determine the species, numbers, and sizes of fish present and potentially susceptible to entrainment during pumpback. Draft tube data were not available for Wallace Dam.

Draft tube surveys at RBR Dam were conducted by WES personnel in February, May, July, September, and November 1988. Draft tube gates were set in place before penstocks were closed to minimize the escape of fish as the water was removed. All fish remaining in the draft tube after dewatering were collected, measured, and weighed. Small fish could have been lost through the grating because the draft tube drain grates had bars with 5.1-cm spacing.

Draft tube data from Truman were collected by USAED, Kansas City, several times per year during routine maintenance, from 1982 to 1988. Draft tubes at Truman were flushed before dewatering to minimize fish capture, and only cursory measurements of fish were made (usually length ranges and number by species) to minimize mortality before fish were returned to the water.

Results of dewatering surveys consisted of numbers of each species (Table 15) and mean lengths or length categories by species (Table 16). Numbers and sizes of fish were much greater at Truman than at RBR even though the draft tubes were flushed at Truman before dewatering surveys. Numbers ranged from 146 to 820 at Truman but only from 8 to 44 at RBR. The 1983 data from Truman were used because corresponding months were available that year for comparison with RBR data. September data are not shown since only 2 fish were collected at RBR Dam (one 16-cm catfish and one 9-cm bluegill).

Summary

Relative biomass was greatest at Truman and then RBR, and lowest at Wallace Dam. Target sizes were largest at Truman and smallest at RBR. Draft tube surveys of fish at Truman and at RBR corroborated acoustic surveys by showing that there were greater numbers of large fish at Truman than at RBR.

Table 15

Comparison of Fish Species and Numbers in Draft Tubes after Dewatering at Truman and RBR Dams. Draft Tubes Were Flushed at Truman but not at RBR

	Number of Fish							
	Truman (1983)				Russell (1988)			
Species	Feb	Jan	Jul	Nov	Feb	May	Jul	Nov
Common carp	1	8	--	--	--	--	--	--
Gizzard shad	2	331	75	--	--	--	--	--
Channel catfish	114	127	36	123	--	--	--	3
Blue catfish	--	124	1	8	--	--	--	--
Flathead catfish	--	37	--	--	--	--	--	18
Buffaloes	2	15	1	--	--	--	--	--
Freshwater drum	9	6	55	15	--	--	--	--
Crappies	39	20	25	--	--	--	--	--
Bluegill	18	111	25	--	--	1	--	--
Paddlefish	1	5	1	--	--	--	--	--
Gars	5	26	--	--	--	--	--	--
White bass	--	10	--	--	--	--	--	--
Threadfin shad	--	--	--	--	41	3	--	--
Shiners	--	--	--	--	1	--	--	--
Yellow perch	--	--	--	--	2	2	18	--
Brown bullhead	--	--	--	--	--	1	1	1
Silver redhorse	--	--	--	--	--	1	--	--
White catfish	--	--	--	--	--	--	1	--

Fish were distributed most deeply in the water column at Wallace, were shallower at Truman, and were shallower still at RBR.

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Leidy, G. R., and R. M. Jenkins. 1977. "The Development of Fishery Compartments and Population Rate Coefficients for Use in Reservoir Ecosystem Modeling," Contract Report Y-77-I prepared by the National Reservoir Research Program, US Fish and Wildlife Service, for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Love, R. E. 1977. "Target Strength of an Individual Fish at Any Aspect, Journal of the Acoustical Society of America, Vol 62, pp 1397-1403.

Table 16

Comparison of Mean Lengths of Fish Taken from Draft Tubes at Truman and RBR Dams After Dewatering. Draft Tubes Were Flushed at Truman but not at RBR

	Length, cm							
	Truman (1983)				Russell (1988)			
Species	Feb	Jan	Jul	Nov	Feb	May	Jul	Nov
Common carp	46	43	--	--	--	--	--	--
Gizzard shad	22	18	--	--	--	--	--	--
Channel catfish	36	37	22*	37	--	--	--	13
Blue catfish	--	56	--	37	--	--	--	--
Flathead catfish	--	69	74*	--	--	--	--	22
Buffaloes	34	56	70*	--	--	--	--	--
Freshwater drum	24	33	20	34	--	--	--	--
Crappies	14	17	--	--	--	--	--	--
Bluegill	14	11	--	--	--	8	--	--
Paddlefish	91	64	119*	--	--	--	--	--
Gars	65	48	--	--	--	--	--	--
White bass	--	18	--	--	--	--	--	--
Threadfin shad	--	--	--	--	5	7	--	--
Shiners	--	--	--	--	10	--	--	--
Yellow perch	--	--	--	--	10	11	13	--
Brown bullhead	--	--	--	--	--	20	11	22
Silver redhorse	--	--	--	--	--	46	--	--
White catfish	--	--	--	--	--	--	17	--

* These mean lengths were calculated from weights using published length-weight equations (Carlander 1969).

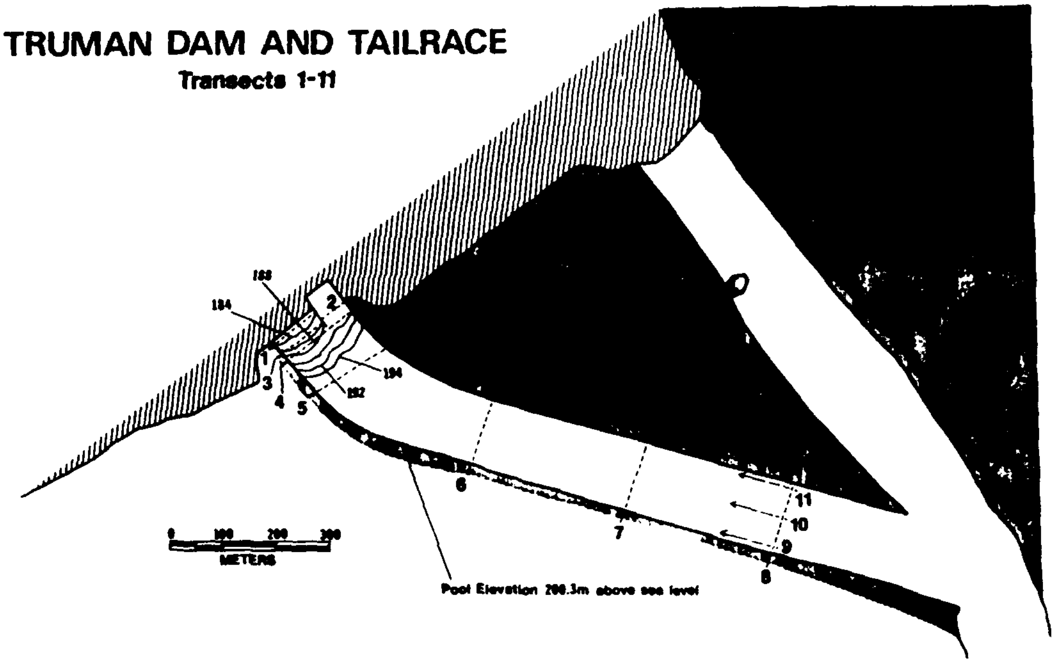

Figure 103. Map of Harry S. Truman Dam and tailrace showing location of hydroacoustic transects surveyed in 1987-1988

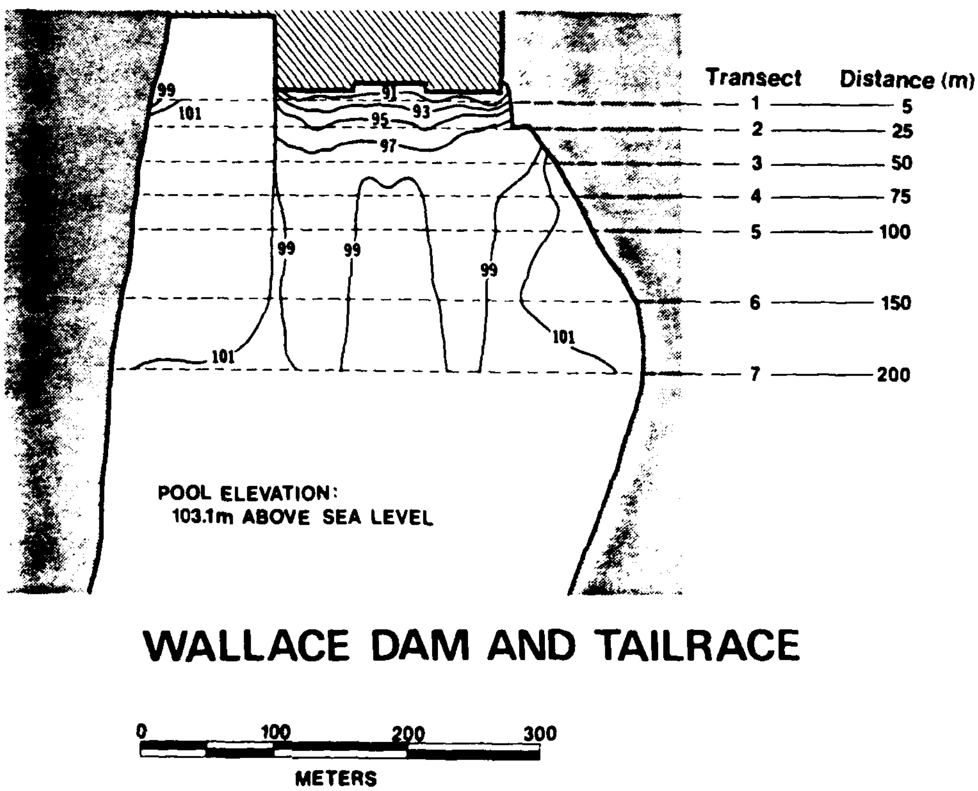

Figure 104. Map of Wallace Dam and tailrace showing location of hydroacoustic transects surveyed in 1988

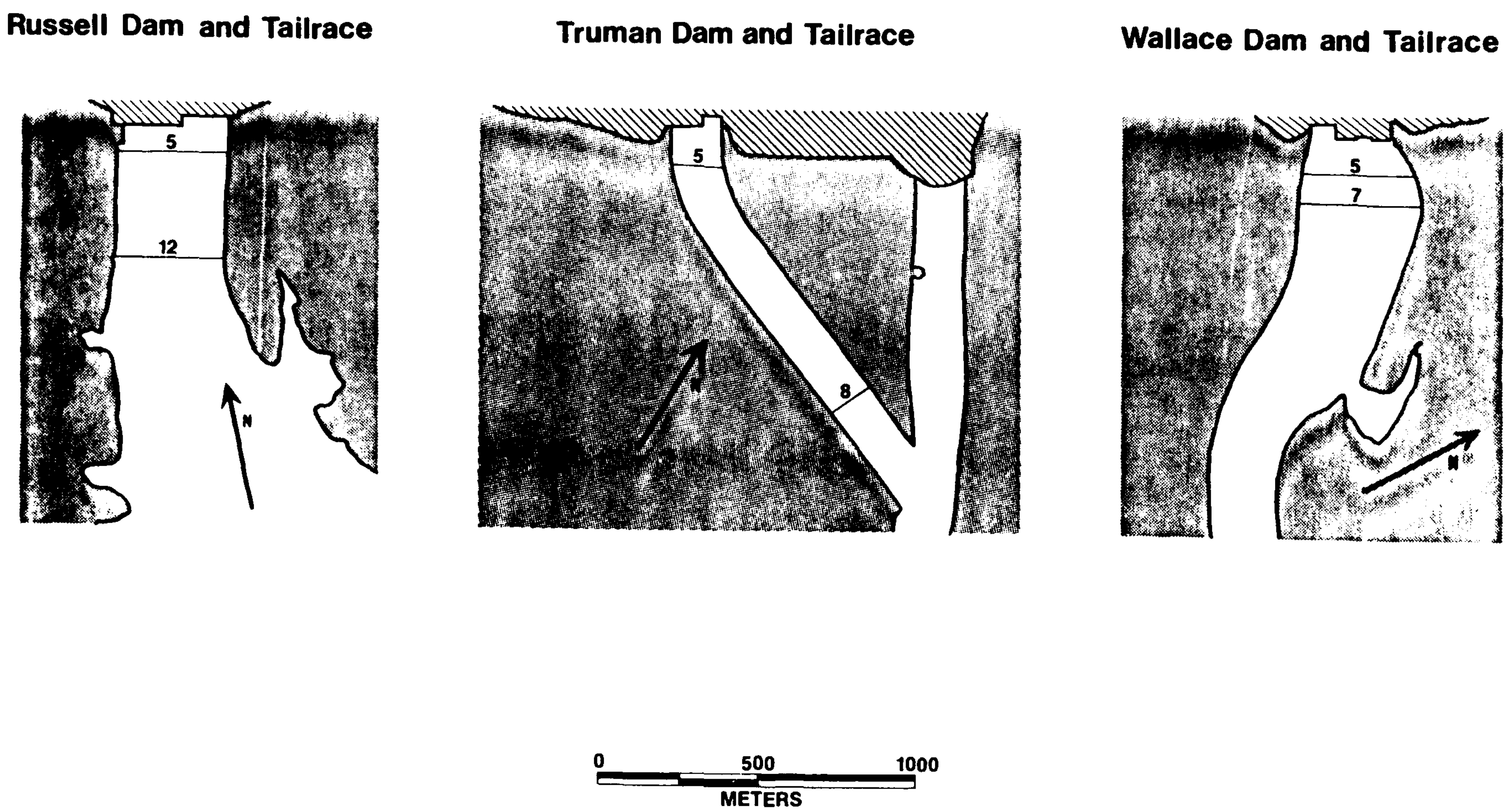

Figure 105. Comparison of RBR, Truman, and Wallace Dams and tailrace regions that were acoustically surveyed. Approximate location of the fifth and last transect is also indicated for comparison

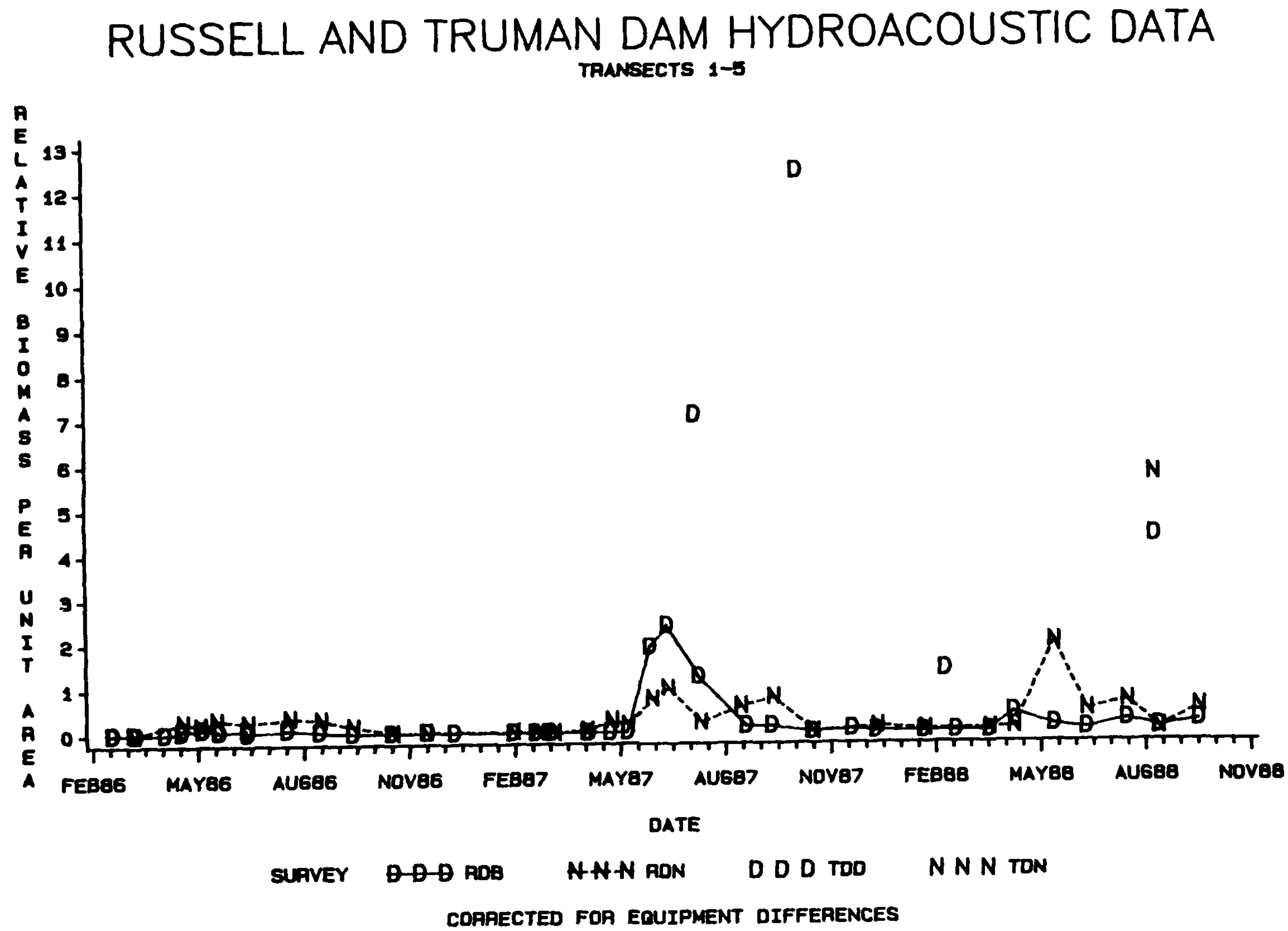

Figure 106. Relative biomass in the RBR tailrace as compared with that in the Truman tailrace. Each point represents the mean of Transects 1-5 at each project during the day (RDB for RBR and TDD for Truman) and at night (RDN for RBR and TDN for Truman)

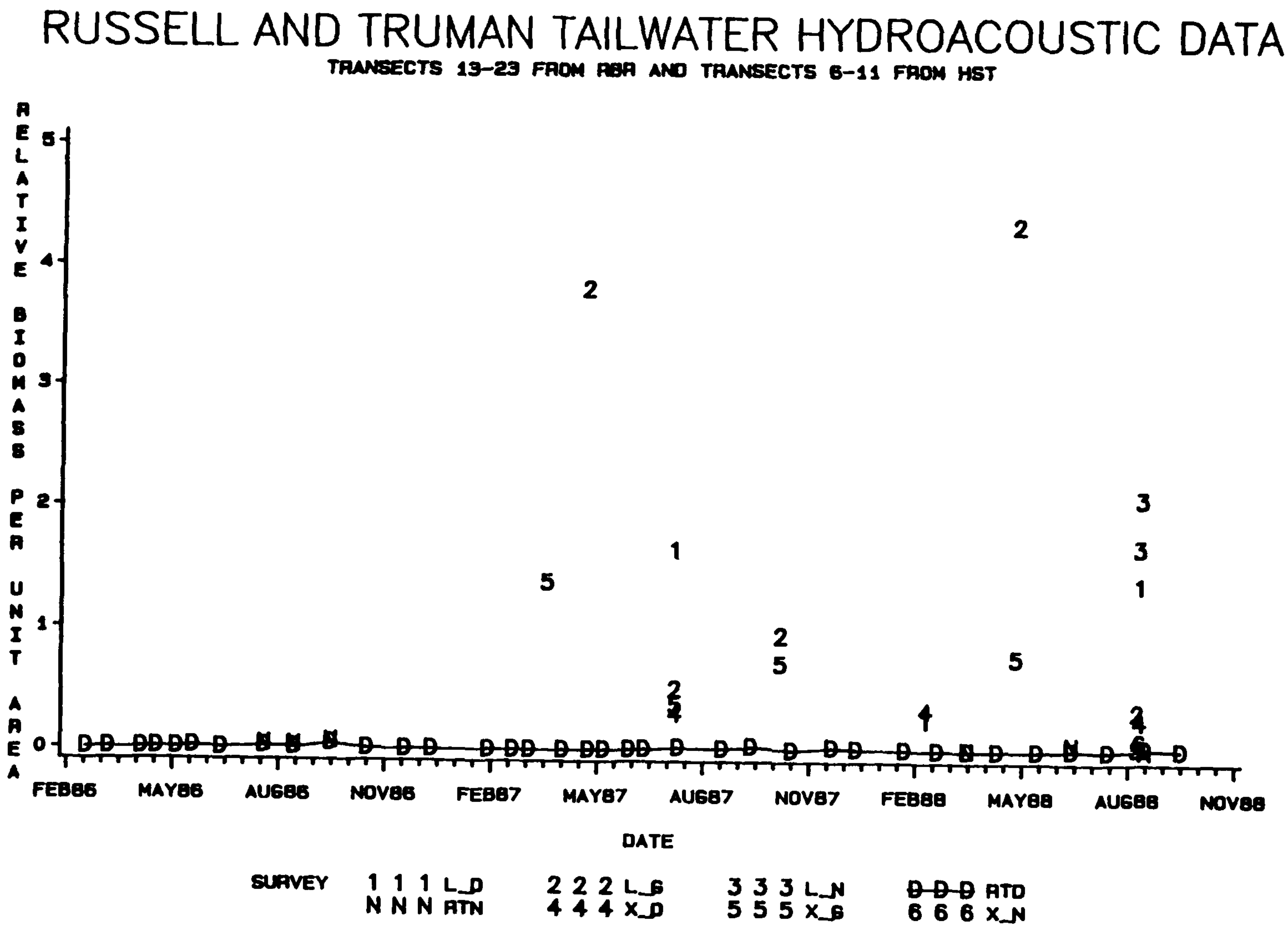

Figure 107. Relative biomass in the RBR tailwater based on daytime (RTD) and nighttime (RTN) sampling of Transects 13-23 as compared with the Truman tailwater based on Transects 6-11. Numbered codes starting with "L" are the longitudinal Transects 9-11 during the day (1 - L_D), during generation (2 - L_G) and at night (3 - L_N). Numbered codes starting with "X" are the cross-section Transects 6-8 during the day (4 - X_D), during generation (5 - X_G) and at night (6 - X_N)

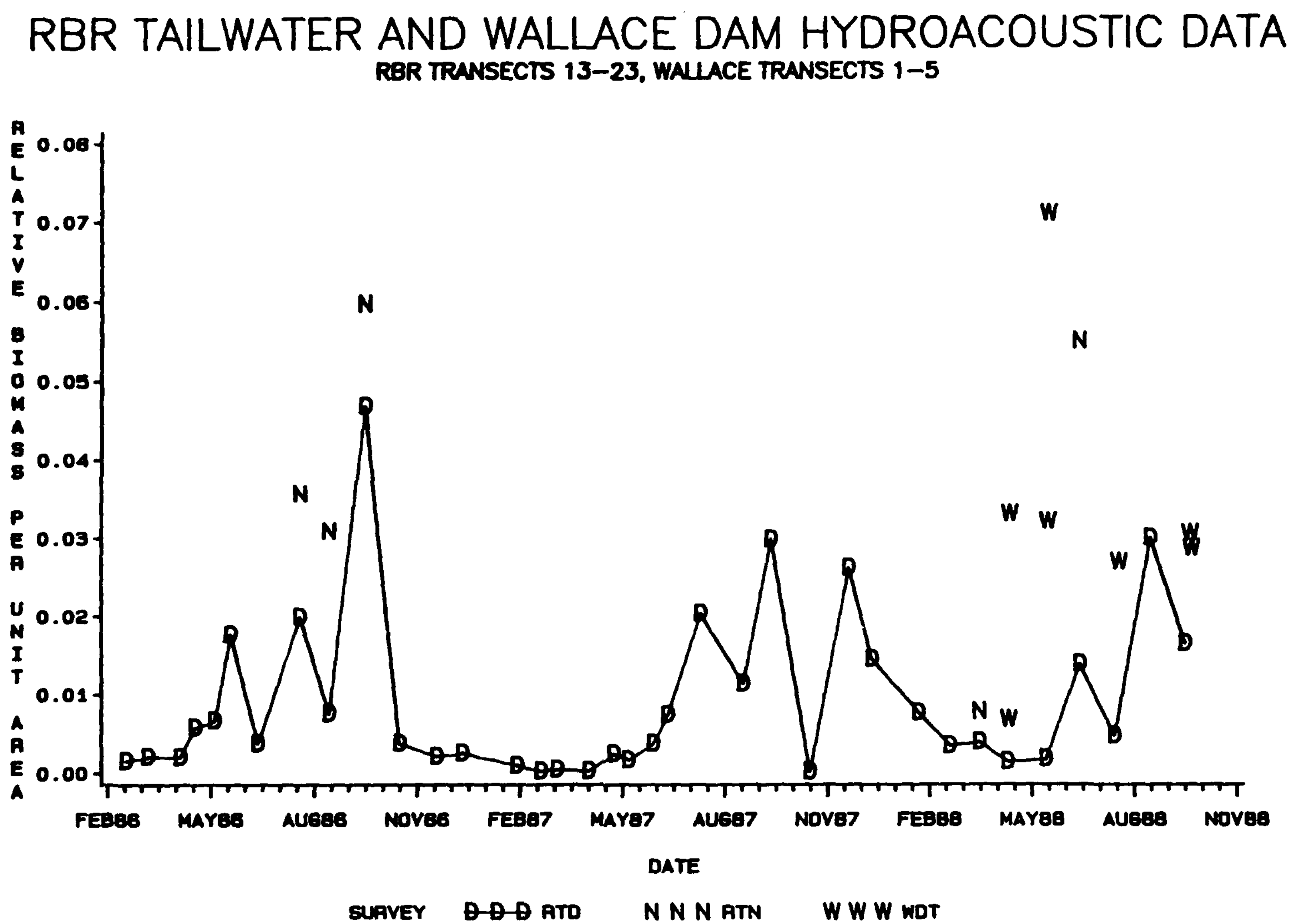

Figure 108. Relative biomass in RBR tailwater Transects 13-23 sampled during the day (RTD) and at night (RTN) in 1986-1988 as compared with Wallace Dam Transects 1-5 in 1988

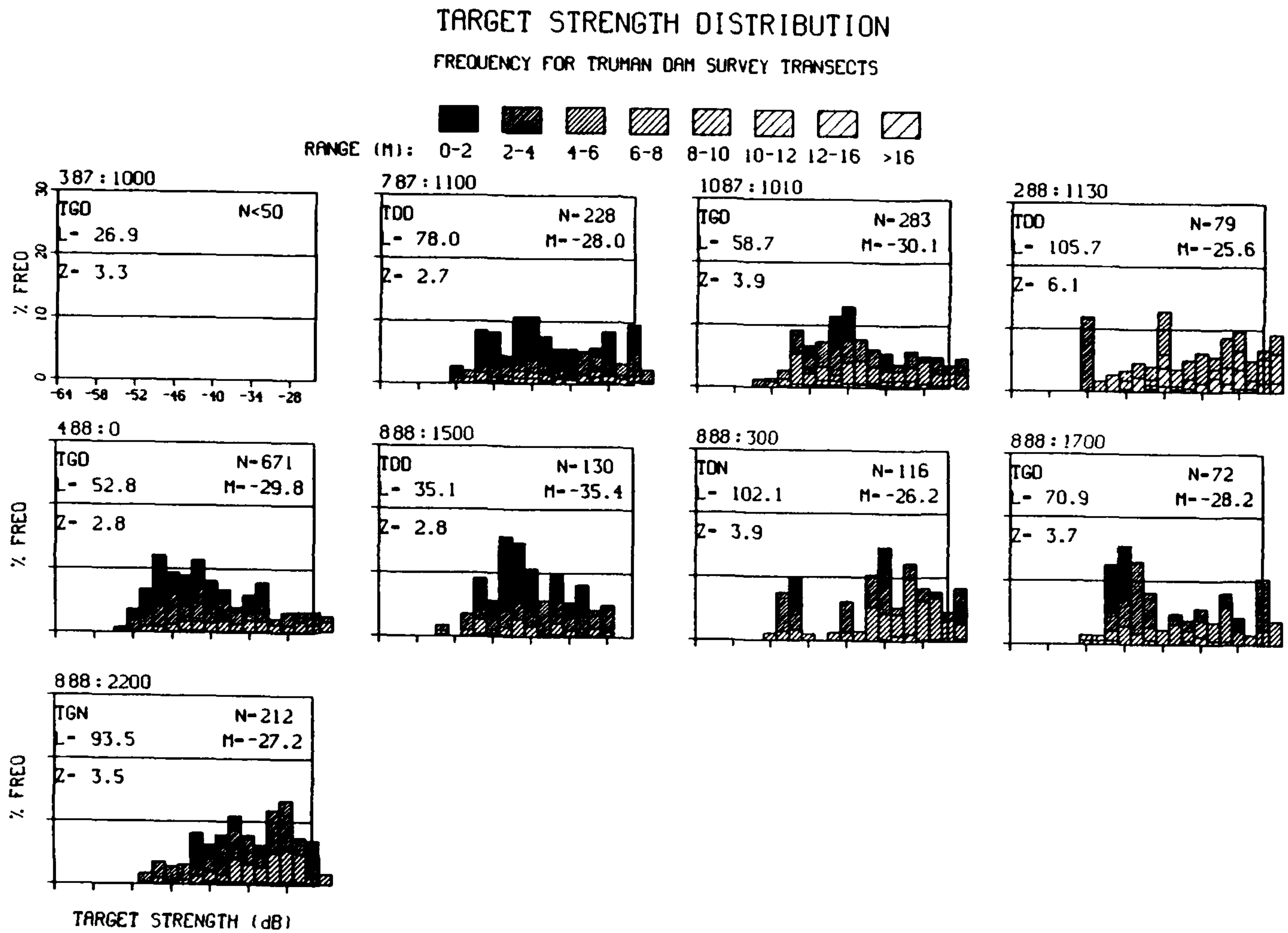

Figure 109. Target strength frequency distribution of fish below Truman Dam in 1987-88. Month, year, and sample start time are indicated above each frame. If the number of single targets (N) was <50, the histogram was not plotted; M = mean target strength (DB); L = mean length (cm), based on Love (1977); Z = mean depth of targets (m), weighted by 1/(range squared)

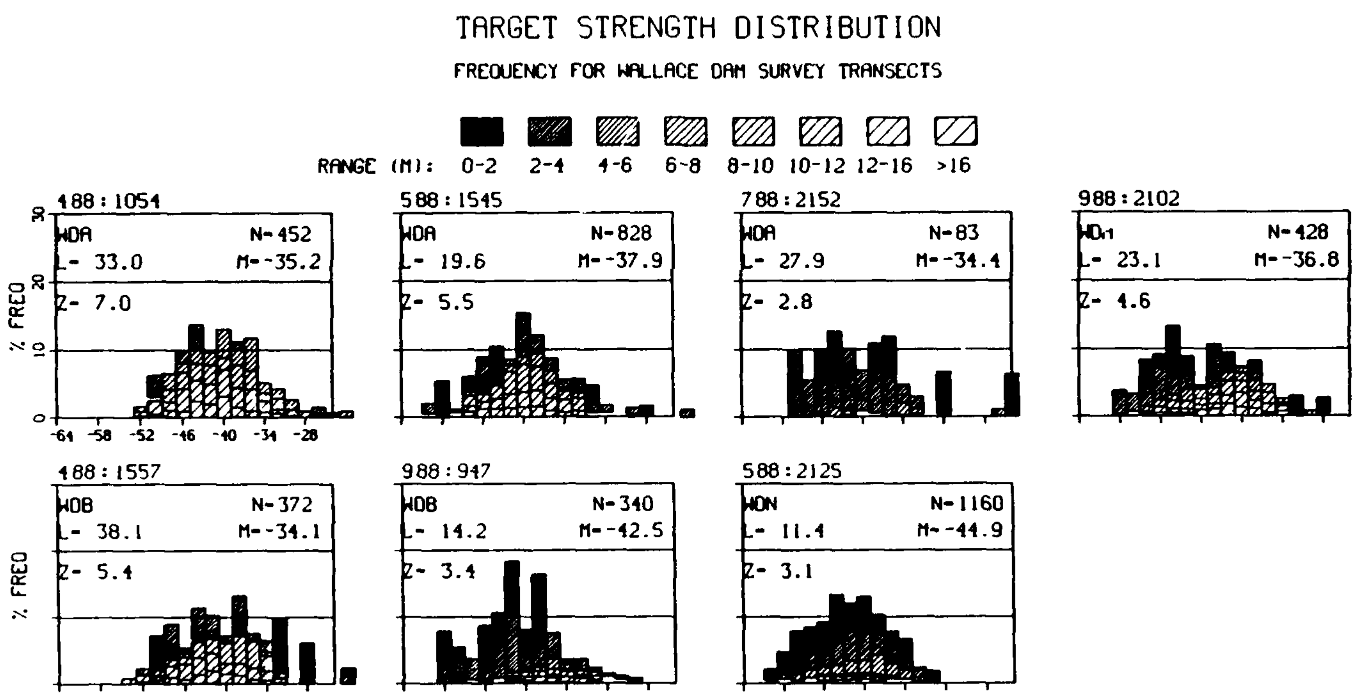

Figure 110. Target strength frequency distribution of fish below Wallace Dam in 1988. Month, year, and sample start time are indicated above each frame. If the number of single targets (N) was <50, the histogram was not plotted; M - mean target strength (DB); L - mean length (cm), based on Love (1977); Z - mean depth of targets (m), weighted by 1/(range squared)

SESSION III: ASSOCIATED STUDY EFFORTS

NUMERICAL MODELING STUDIES OF J. STROM THURMOND LAKE

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Planned Studies

The numerical modeling studies will address effects of proposed pumpback operations at RBR Dam and channel improvements in the tailrace on velocities, temperature, dissolved oxygen, turbidity, and ichthyoplankton in the upper 10 km of JST Lake. The area includes RBR tailwater and Russell Creek and Broad River tributaries.

Previous studies have shown that variations in physical, chemical, and biological parameters are three dimensional (3-D) in nature. Two-dimensional (2-D) models will be used to investigate 3-D responses of physicochemical and biological parameters, because a 3-D model capable of economically simulating responses does not currently exist. Longitudinal and vertical variations of all parameters will be studied with CE-QUAL-W2, while TABS II will be used to examine longitudinal and lateral variations in velocities, turbidity, and ichthyoplankton. CE-QUAL-W2 is a 2-D, laterally averaged model that predicts water-surface elevations, velocities, temperatures, and constituent concentrations in the longitudinal and vertical directions. Lateral averaging assumes that lateral variations in these parameters are negligible. Simulations will be conducted during spring and summer for high- and low-pool conditions (proposed changes are shown in bold type):

	no pumpback	no channel improvement
high pool		channel improvement
	pumpback	no channel improvement
		channel improvement
	no pumpback	no channel improvement
medium pool		channel improvement
	pumpback	no channel improvement
		channel improvement

Spring simulations will include velocities, temperature, dissolved oxygen, turbidity, and ichthyoplankton. Summer simulations will include velocities, temperature, and dissolved oxygen. Ichthyoplankton will not be included in summer simulations because their densities are greatly reduced by the end of June. All simulations will include "worst case scenarios" to assess maximum adverse impacts of the proposed changes on the tailwater region of JST Lake.

RECENTLY COMPLETED AND PLANNED BEHAVIORAL WORK

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Introduction

Work has begun on evaluations of high- and low-frequency sound as candidate behavioral barriers to prevent or minimize fish entrainment and mortality in turbines at RBR Dam. The work is separated into two coordinated research efforts conducted separately by the WES and Sonalysts, Inc. The work conducted by Sonalysts, Inc., is sponsored by the New York Power Authority (NYPA). Findings are regularly exchanged between the WES and the NYPA.

Projects

The work by Sonalysts, Inc., features high-energy, low-frequency sound evaluations conducted on *Morone saxatilis* (striped bass) and *Morone americana* (white perch). The work by the WES features evaluations of high-frequency sound performed primarily on *Alosa aestivalis* (blueback herring). Personnel from WES plan to verify significant findings that were made by Sonalysts, Inc., and that may have application on striped bass and hybrid bass at RBR.

The high-frequency work of the WES is based on preliminary results obtained by Messrs. Al Menin of Bendix Corporation and Tom Curtis of South Carolina Wildlife and Marine Resources Department at Stevens Dam, South Carolina. In their work, they discovered that blueback herring respond dramatically, consistently, and at some distance to constant, high-frequency sound at 120 kHz. In fact, blueback herring within approximately 6 ft of the transducer were killed or stunned in their tests.

Testing by WES was performed in the cove next to the Resource Manager's Office in RBR Lake. The testing facility consisted of a 20- by 8-ft work platform on which a roofed work and observation area was constructed. The work area had 4-ft walls and a Plexiglas observation window for viewing the

response of blueback herring held captive in an attached net enclosure. The enclosure consisted of a 20- by 4- by 4-ft nylon holding net suspended from a floating 2-in. polyvinyl chloride (PVC) frame. The frame corners were rounded with two 45-deg EL joints instead of a single 90-deg EL to prevent blueback herring from becoming trapped in the corners of the net. The bottom of the net was covered with a submerged frame constructed of 1-in. PVC pipe. The bottom frame had PVC cross members that provided visual borders to four quadrants of equal size (4 by 5 ft). White cotton sheeting was stretched across the bottom frame to provide a high contrast bottom for increasing the visibility of the fish. The long axis of the net was attached parallel to the long axis of the work platform. The sound equipment was located under the roofed observation area, and transducers were submerged just outside one end of the net. An observer on the work platform could clearly observe and record the quadrant distribution of fish within the holding net.

The tests conducted by WES personnel were separated into the following six steps:

- a. Determination the time interval required between sound tests for the fish to respond in a manner similar to naive fish (fresh fish could not be used for every test because of the difficulty in obtaining blueback herring).
- b. Observation of the response of blueback herring to a range of high frequencies to determine the optimum frequencies for repelling blueback herring from the RBR Dam.
- c. Based on the results of Step b, engineering either simple or complex sounds that appear most effective for repelling blueback herring.
- d. Determination of the optimum firing sequence of the engineered sound from Step c to minimize acclimation by blueback herring.
- e. Determining the distance of effectiveness of the sound signal.
- f. Evaluation of the ability of the optimal signal to disrupt the distribution of fish in the immediate tailwater. This evaluation will be made as part of routine mobile hydroacoustic sampling conducted in the tailwater.

The WES investigators are presently about half way through Step a in this design. Tentatively, at the present power settings, WES personnel feel that approximately 45 min is required between tests before the response of previously tested blueback herring is similar to the initial naive response. This time frame is consistent with that (40 min) used by personnel from Ontario Hydro, Ltd. during their evaluations of sound-based behavioral barriers.

Design of a prototype fish protection system for RBR Dam will require integrating knowledge of the spatial and temporal distribution of fish, water

quality patterns, and predicted hydraulic conditions in the tailwater. In the current plan, WES personnel will attempt to repel blueback herring away from potentially entraining flows in front of the pumped-storage turbine draft tubes and attract them towards eddies and slack water areas where they should be safe from entrainment.

PHYSICAL MODEL STUDY OF RICHARD B. RUSSELL DAM FISH PROTECTION SYSTEM

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Purpose

Fishery studies of the RBR Project indicate that a relatively large and diverse fish community inhabits the tailwater region, potentially subjecting them to entrainment during pumped-storage operations. Many of the fish protection systems currently under consideration would be located in this area. One potential alternative for preventing fish entrainment is a bar rack system located just downstream of the powerhouse.

A physical model study of the bar rack system, also referred to as the Fish Protection System (FPS), is currently being conducted by the Hydraulics Laboratory of the WES. The specific information needed from the study are:

a. The optimum distance from the draft tube entrance to the bar rack system.

b. The 3-D flow patterns in the tailrace with and without the bar rack system in place during pumpback operations.

c. The 3-D velocity distribution in the tailrace with and without the bar rack system in place during pumpback operations.

d. Head losses through the bar rack system during the pumpback and generating modes and the effects of debris clogging.

e. Operational guidance on the removal of the bar racks during the generating mode if the head losses are excessive.

Modeling Procedure

Initially, three separate models were proposed to determine the necessary information. A 1:25-scale model was recommended for determining the location of the FPS and the flow distribution in the vicinity of the bar racks during pumpback operations. This model could not be used to quantify head loss through the FPS because of scale effects with low flow through the small openings in the bar racks. Various scales of sections of the FPS were tested in a 2.5-ft-wide flume in an effort to determine a model scale that could be

used to quantify head losses. The tests indicated the model to prototype ratio needed to be less than 1:4. A model of this scale was not feasible for laboratory testing, so the third model, which would have been a section model of one pump-turbine unit and a section of the tailrace, was not constructed.

Model Description

The 1:25-scale model reproduced approximately 900 ft of the tailrace, the draft tubes for pump-turbine Units 5-8, a geometric representation of the downstream face of the powerhouse for Units 1-4, and a 200-ft-wide area (adjacent to Unit 8) of the downstream face of the spillway. The topography in the tailrace was constructed of sand and cement mortar and was molded to sheet metal templates. The templates represent cross-section data obtained from soundings of the tailrace acquired by the Environmental Laboratory of WES. Figure 111 shows bottom elevations in the RBR tailrace area between 40 and 60 ft from the powerhouse. Model topography represents a fairly clean earth channel. The draft tubes for the pump-turbine units were constructed of very smooth plastic. The face of the powerhouse and spillway was constructed of plastic-coated plywood, and the powerhouse piers were constructed of wood and treated with a waterproofing compound to prevent swelling.

Water used in operation of the model was supplied by a circulating constant-head system. Discharges were measured with venturi meters installed in the inflow lines and baffled before entering the model. Water-surface elevations were measured using point gages referenced to a known datum. Stilling wells connected to piezometers were utilized in areas where surface turbulence was significant. Velocities were measured using a Nixon streamflow, series 400 propeller type flowmeter. Velocities as low as 0.08 ft/sec can be measured with a reported accuracy of 1 percent of the true velocity. The instrument was checked periodically to verify the velocity measurements.

Results of Pumpback Test

Initial tests were conducted to determine the velocity distribution in the vicinity of the proposed location of the FPS with all four units operating and tailrace water-surface elevations of 320 (an intermediate pool), 312 (minimum conservation pool), and 330 (normal conservation pool). Velocities

were obtained at various depths of the flow at distances of 5, 15, 25, 40, and 50 ft from the downstream face of the powerhouse. Station numbers were assigned at designated areas in the tailrace to identify velocity measurement locations. For example, Stations 2-6 cover the area from center line to center line of adjacent piers for Unit 5 (Figure 112).

Units 5-8 without FPS

The first tests were conducted without the FPS in place, with all four units operating, and a tailrace-surface elevation of 330 ft. The test condition was obtained by setting the correct discharge for all four units operating (27,820 cfs) and adjusting tailrace elevation to 330 ft by manipulating a tailgate. Based on velocity measurements obtained upstream (during pumpback) from the draft tubes, slightly more flow approached Unit 8 with the remaining flow evenly distributed between Units 5-7. Velocities measured 1, 20, and 35 ft off the bottom are shown in Figures 113-115, respectively. Velocity profiles recorded 15 ft from the face of the powerhouse throughout the depth of flow at Stations 11 and 17 indicate higher velocities at Station 17, which is the approach flow to Unit 8 (Figure 116). The profile shown at Station 11 was fairly typical of the flow conditions for Units 5-7. Flow accelerates as it approaches the intakes in the lower 20 ft of the flow depth and decelerates as it approaches the intakes in the upper portion of the flow. The average velocity computed from measurements obtained throughout the flow depth 40 ft from the face of the powerhouse was 1.7 ft/sec, and 50 ft from the face of the powerhouse the average velocity was 1.3 ft/sec. Tests conducted without the FPS in place for all four pumpback units operating with a tailrace water-surface elevation of 320 indicated that velocities in the lower 20-ft depth of flow were about the same as those observed with a tailrace water-surface elevation of 330 and the velocities in the upper portion of the flow were on the order of 0.2 to 0.6 ft/sec higher than those observed with the tailrace water surface of 330. Due to the time constraint in obtaining results, the number of velocities measured with a tailrace water-surface elevation of 320 was reduced from those obtained with the tailrace water-surface elevation of 330. The average velocity computed from measurements obtained 40 ft from the face of the powerhouse with the tailrace water surface at el 320 was 2.0 ft/sec, and 50 ft from the face the average velocity was 1.9 ft/sec.

Tests performed with a tailrace water-surface elevation of 312 indicated the velocities were higher throughout the entire depth than those observed with a tailrace water surface of 320.

Units 5-8 with FPS

Tests were conducted next with the FPS installed in the model. The structural members were constructed of wood, and the frames for the fish rack were fabricated from plastic. A schematic of the FPS is shown in Figure 117. Results from previous section model tests indicated that scale effects were encountered in modeling the bar rack for the FPS. The geometry of the rack in this 1:25-scale model could not be reproduced similar to the prototype because of the physical constraints of constructing a bar 0.02 in. thick. Initially, the model rack was constructed of metal plate with 40-percent porosity. Comparative tests conducted with metal plates of different porosity indicated the velocity upstream from the rack was not affected by the difference in porosity; therefore, a velocity distribution similar to the prototype structure could be obtained.

The first tests with the FPS were conducted with all four units operating and a tailrace water-surface elevation of 320. Based on velocity measurements obtained from flow entering the draft tubes, approximately 30 percent of the flow was observed entering Unit 8, and flow through the other units appeared to be uniformly distributed. Approach velocities measured as close to the FPS as the velocity probe allowed (approximately 2 ft upstream) indicated the velocities ranged from 1.5 to 4.8 ft/sec. The higher velocities were measured at the end units and resulted from flow accelerating around the end walls. The average velocity computed from 135 measurements upstream from the rack was 2.6 ft/sec.

Tests conducted with all four units operating and a tailrace water-surface elevation of 330 indicated velocities upstream from the FPS ranged from 1.1 to 5.1 ft/sec with the higher velocities measured at the end walls. Velocities measured 1, 20, and 35 ft off the bottom with these test conditions are shown in Figures 118-120, respectively. Overall velocities were lower than those observed with a tailrace water-surface elevation of 320, and the average velocity computed from 165 measurements taken upstream from the rack was 2.3 ft/sec.

Tests conducted with all four units operating and a tailrace water-surface elevation of 312 indicated velocities upstream from the FPS ranged

from 1.7 to 5.5 ft/sec and were higher in practically all comparable locations to those observed with a tailrace water-surface elevation of 320. The average velocity computed from 105 measurements obtained upstream from the rack was 3.3 ft/sec.

Units 6 and 7 with FPS

Tests were conducted next with only Units 6 and 7 operating. Velocities measured during these tests for tailrace water-surface elevations of 330 and 320 indicated the maximum velocity measured upstream from the FPS for tailrace water-surface elevations of 330 and 320 was 2 ft/sec and occurred at Stations 6 and 10 when the tailrace water-surface elevation was 320. The average velocities computed from measurements obtained upstream from the rack were 1.1 ft/sec with a tailrace water-surface elevation of 330 and 1.3 ft/sec with a tailrace water-surface elevation of 320. The maximum velocity measured upstream from the FPS with the tailrace water-surface elevation at 312 was 3.6 ft/sec and occurred at Station 6. Velocities in comparable locations were higher when the tailrace water-surface elevation was 312. The average velocity computed from measurements obtained upstream from the rack was 2.0 ft/sec. Velocities measured 1, 20, and 35 ft off the bottom with a tailrace water-surface elevation of 330 are shown in Figures 121-123, respectively.

Units 5, 6, and 7 with FPS

Tests were also conducted with Units 5, 6, and 7 operating. The average velocities computed from measurements taken upstream from the rack with tailrace water-surface elevations of 330, 320, and 312 were 1.8, 1.9, and 2.6 ft/sec, respectively. The highest velocity measured upstream of the FPS for these tests was 4.2 ft/ sec and occurred near Station 15 (where flow approached Unit 7) with a tailrace water-surface elevation of 312.

FPS 50 percent clogged

The effect of debris clogging the rack was observed in the model by intentionally blocking 50 percent of the flow area through the racks. The top 25 percent and bottom 25 percent were blocked to simulate clogging from floating debris and sunken debris. The first of these tests was conducted with a tailrace water-surface elevation of 320. The average velocity computed from measurements obtained upstream from the rack throughout the entire depth was 2.6 ft/sec, the same as computed without the rack clogged. The average velocity computed for the flow in the middle 50 percent of the rack was

3.2 ft/sec, an increase of 0.6 ft/sec over that for comparable locations without any clogging. The average velocity computed for the flow in the middle 50 percent of the rack with only Units 6 and 7 operating was 1.8 ft/sec, an increase of 0.5 ft/sec over that for comparable locations without any clogging. The average velocity computed for the flow in the middle 50 percent of the rack with Units 5, 6, and 7 operating was 2.6 ft/sec, an increase of 0.6 ft/sec over that for comparable locations without the rack clogged.

Test results conducted with a tailrace water-surface elevation of 330 and the racks 50 percent clogged indicated that the average velocities computed for flow in the middle 50 percent of the racks were 3.1 ft/sec with all four units operating, 1.7 ft/sec with Units 6 and 7 operating, and also 1.7 ft/sec with Units 5, 6, and 7 operating. The average velocities increased over those with clean racks with Units 5-8 and Units 6 and 7 operating at 0.6 ft/sec and remained the same with Units 5, 6, and 7 operating. Figure 124 presents average velocities determined in tests with the FPS clogged.

Modifications to FPS

Tests were conducted with the end walls extended 25 ft farther into the tailrace to try and reduce the velocity at the rack by moving the flow contraction around the pier away from the vicinity of the rack. The flow contraction that occurred with this modification was strong and actually caused an eddy to form at the rack near the end walls. Velocities near the rack were higher at some locations than those measured without the wall extensions; so this modification was not acceptable.

A bar rack was placed in front of Unit 4, and the end wall was moved between Units 3 and 4 instead of 4 and 5 to try and reduce the velocities at the rack in front of Unit 5. The maximum velocity measured in front of the rack for Unit 5 was reduced from 4.1 to 2.0 ft/sec, and the average velocity for the first rack section for Unit 5 was reduced from 2.6 to 1.5 ft/sec (Figure 125). This was considered to be an appropriate alternative for reducing the velocities in front of the rack for Unit 5.

Conclusions

Comparison of the velocity distributions with and without the FPS (Figures 126-129) indicated that the presence of the FPS caused an increase in

the velocities 40 to 50 ft from the face of the powerhouse. This is attributed to the reduction in approach area when the FPS was installed and also localized increases caused by flow accelerations around the structural piers, end walls, and members of the FPS.

No significant reduction in approach velocities would be gained by moving the bar rack from its original location.

Velocities approaching the bar rack were reduced appreciably by reducing the number of units operating (Figures 130-132).

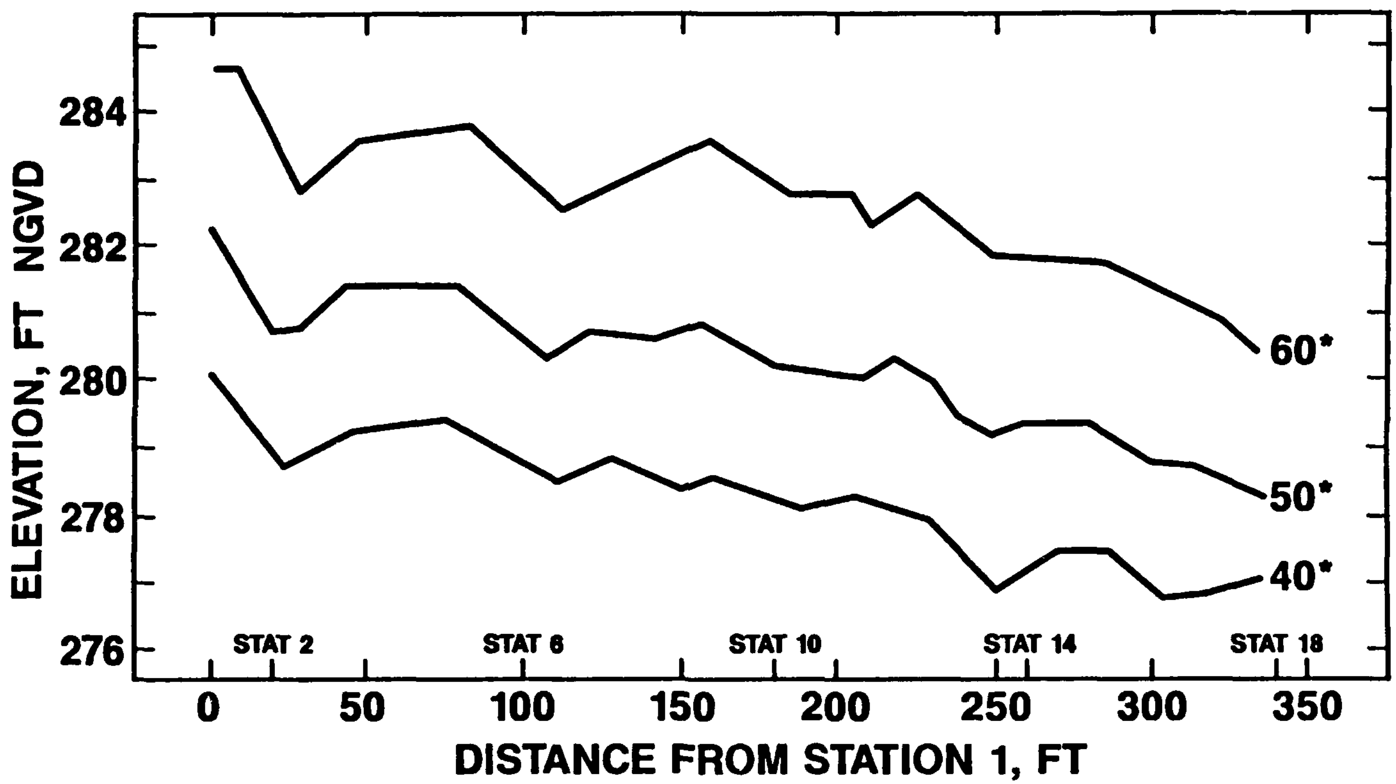
Velocities measured in comparable locations for the three tailrace water-surface elevations without the FPS installed were higher as the water-surface was lowered (Figures 133-135). This was more evident near the surface and occurred to a lesser degree in the lower depths.

Tests with and without the FPS installed indicated that approximately 28 to 30 percent of the total flow approaches Unit 8 and the flow distribution among the other three units was fairly uniform.

Surface and bottom clogging of the bar racks causes an increase in the approach velocities in the area where the racks are not clogged.

The approach velocity to the racks for Unit 5 could be reduced by installing a bar rack arrangement in front of Unit 4.

Approach velocities to Unit 8 probably could be reduced by providing a curvilinear shaped training wall; however, the wall would adversely affect spillway flows. Streamlining pier noses of the FPS would reduce the flow contractions, but would not cause a significant reduction in the approach velocity at the racks near the piers.



*DISTANCE IN FT FROM POWERHOUSE

Figure 111. Bottom elevations in Russell Tailrace between 40 and 60 ft from the powerhouse

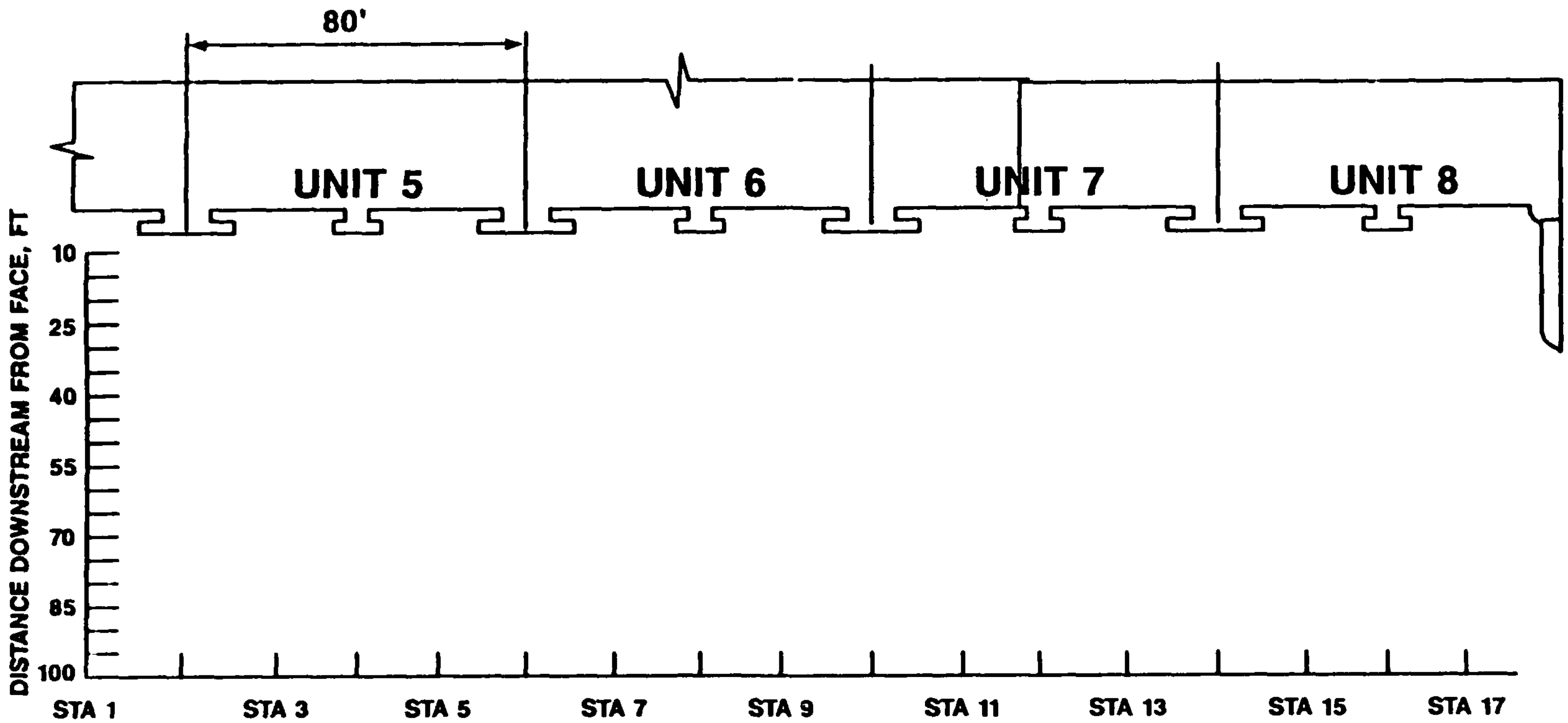
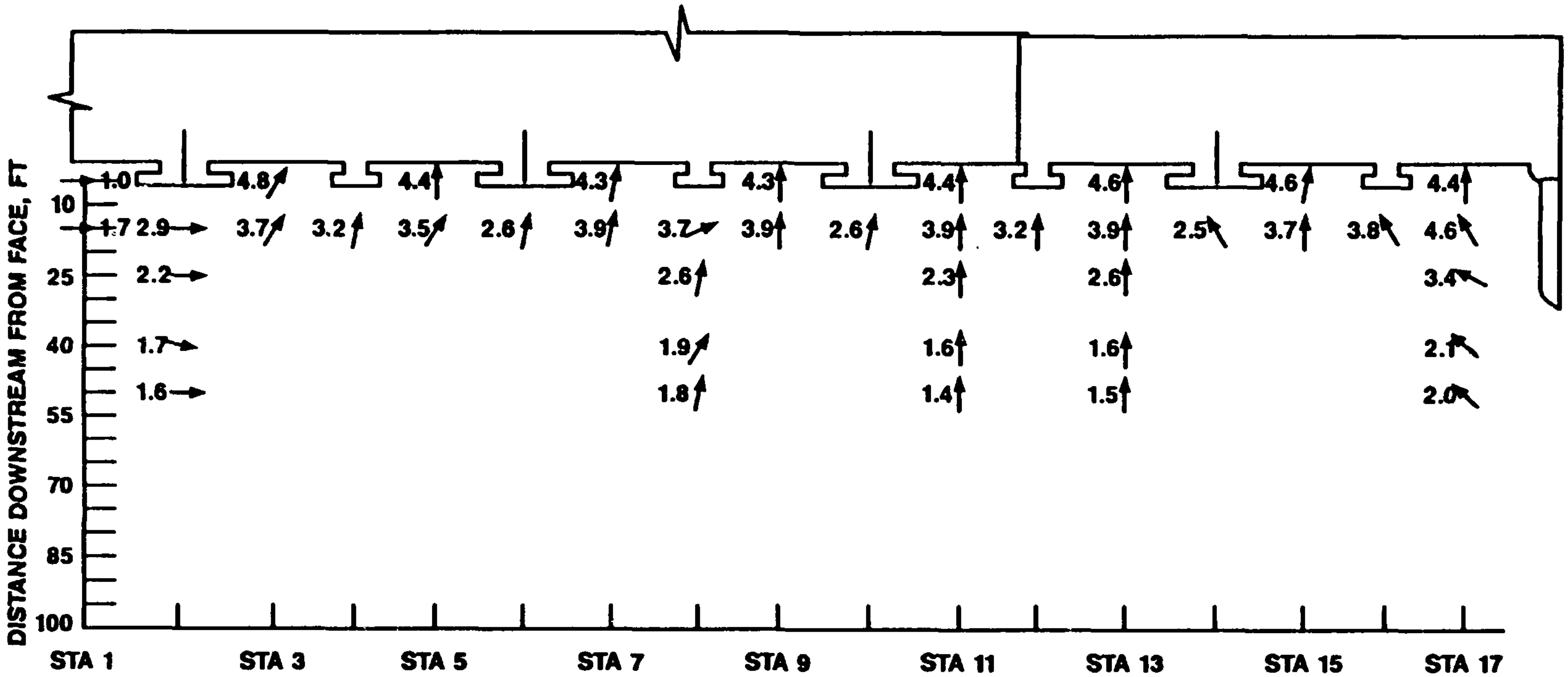
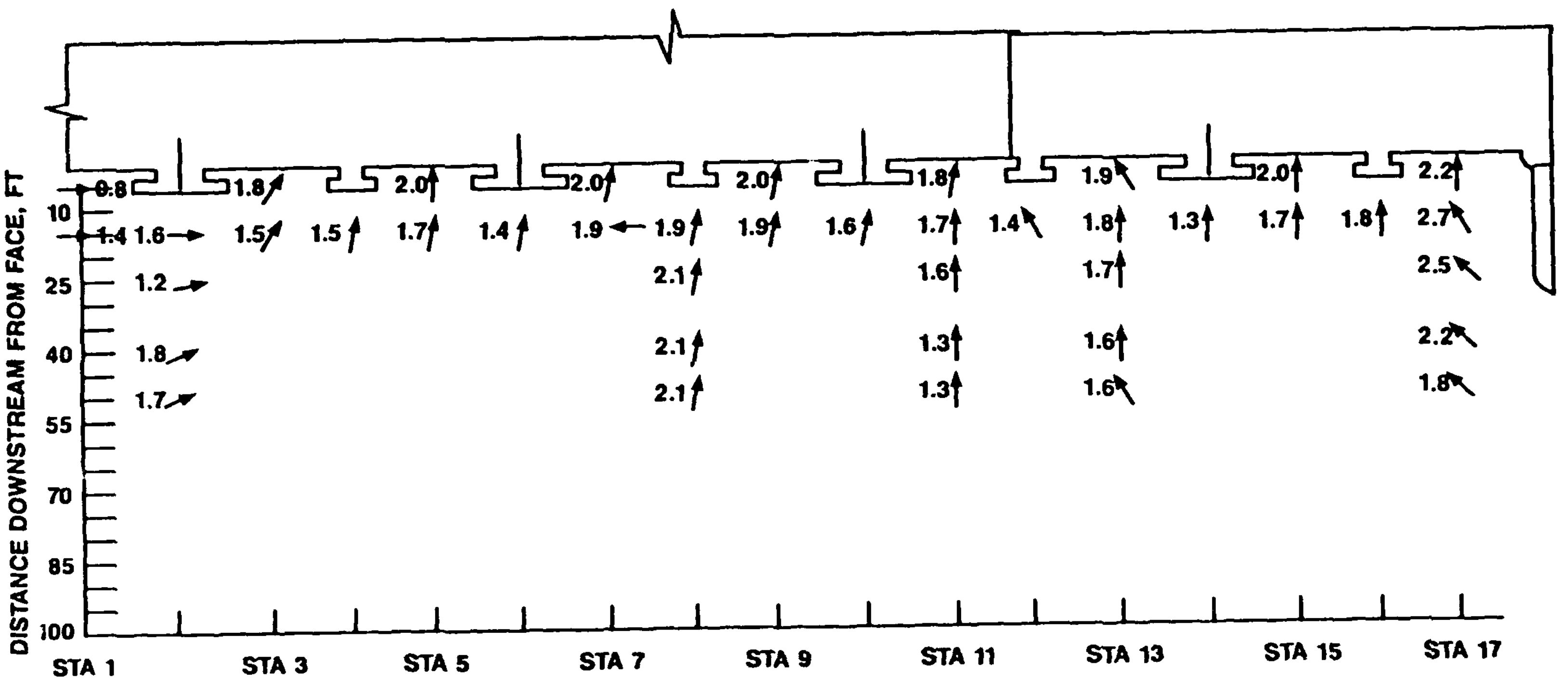


Figure 112. Stations used for measuring velocities in the RBR tailrace



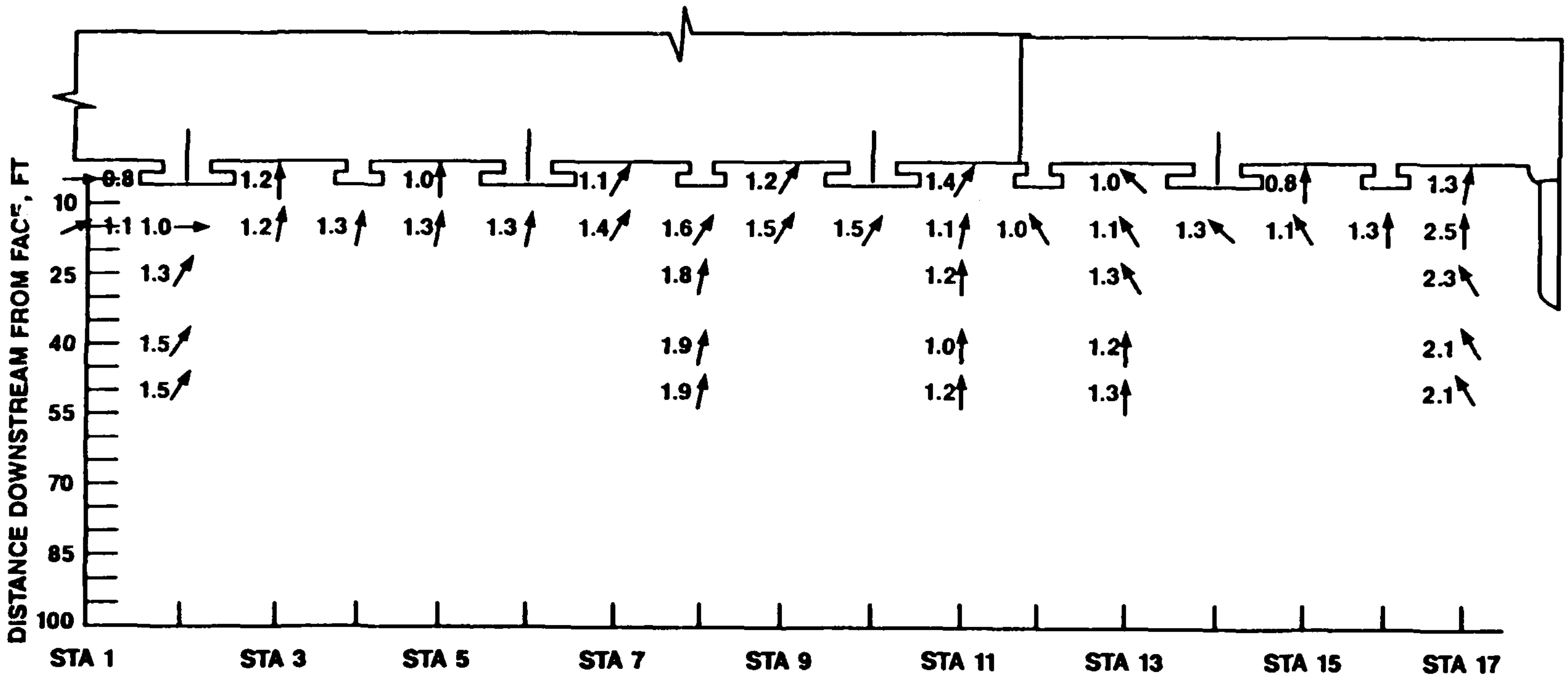
NOTE: VELOCITIES ARE IN FT/SEC

Figure 113. Velocities measured 1 ft off the bottom at various distances downstream from the face of the dam, with all four units operating (27,820 cfs), a tailrace water-surface elevation of 330, and no FPS



NOTE: VELOCITIES ARE IN FT/SEC

Figure 114. Velocities measured 20 ft off the bottom at various distances downstream from the face of the dam, with all four units operating (27,820 cfs), a tailrace water-surface elevation of 330, and no FPS



NOTE: VELOCITIES ARE IN FT/SEC

Figure 115. Velocities measured 35 ft off the bottom at various distances downstream from the face of the dam, with all four units operating (27,820 cfs), a tailrace water-surface elevation of 330, and no FPS

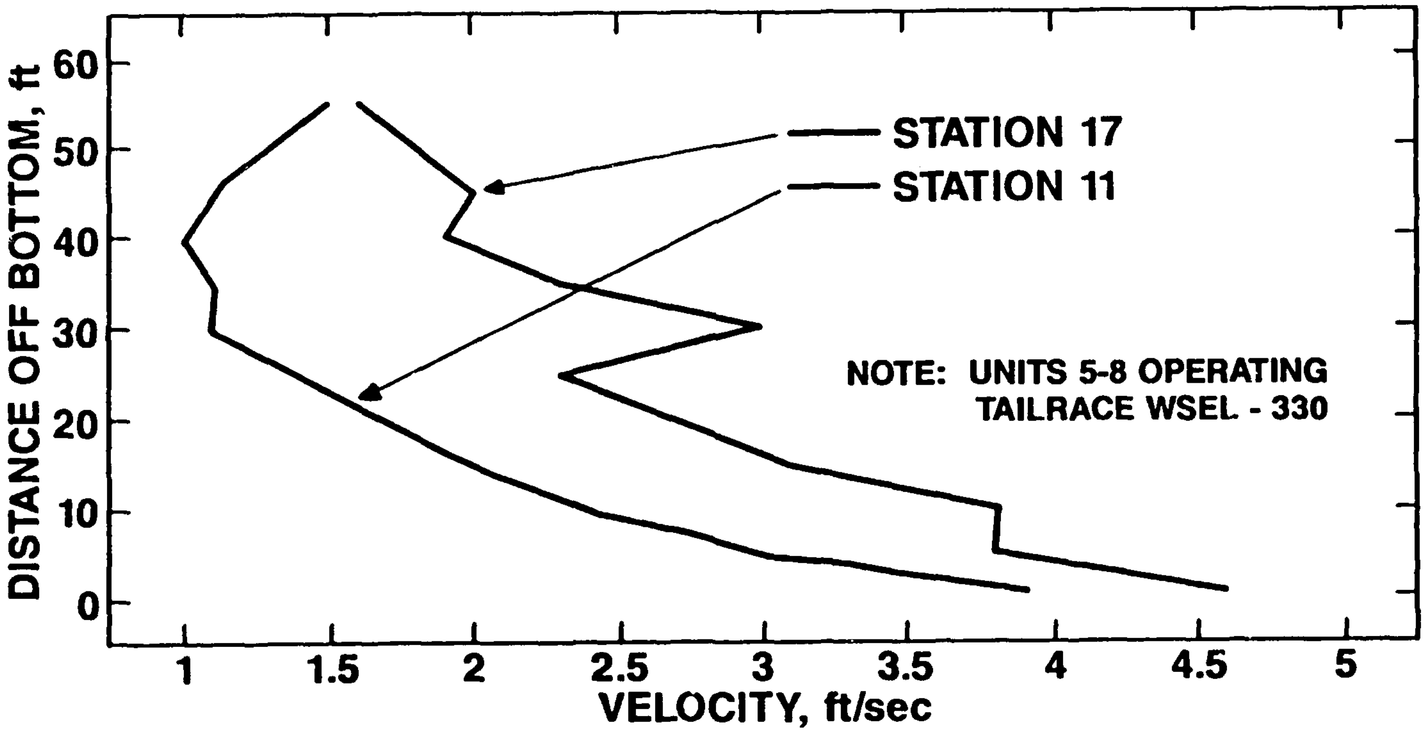


Figure 116. Velocity profiles recorded 15 ft from the face of the powerhouse throughout the depth of flow at Stations 11 and 17

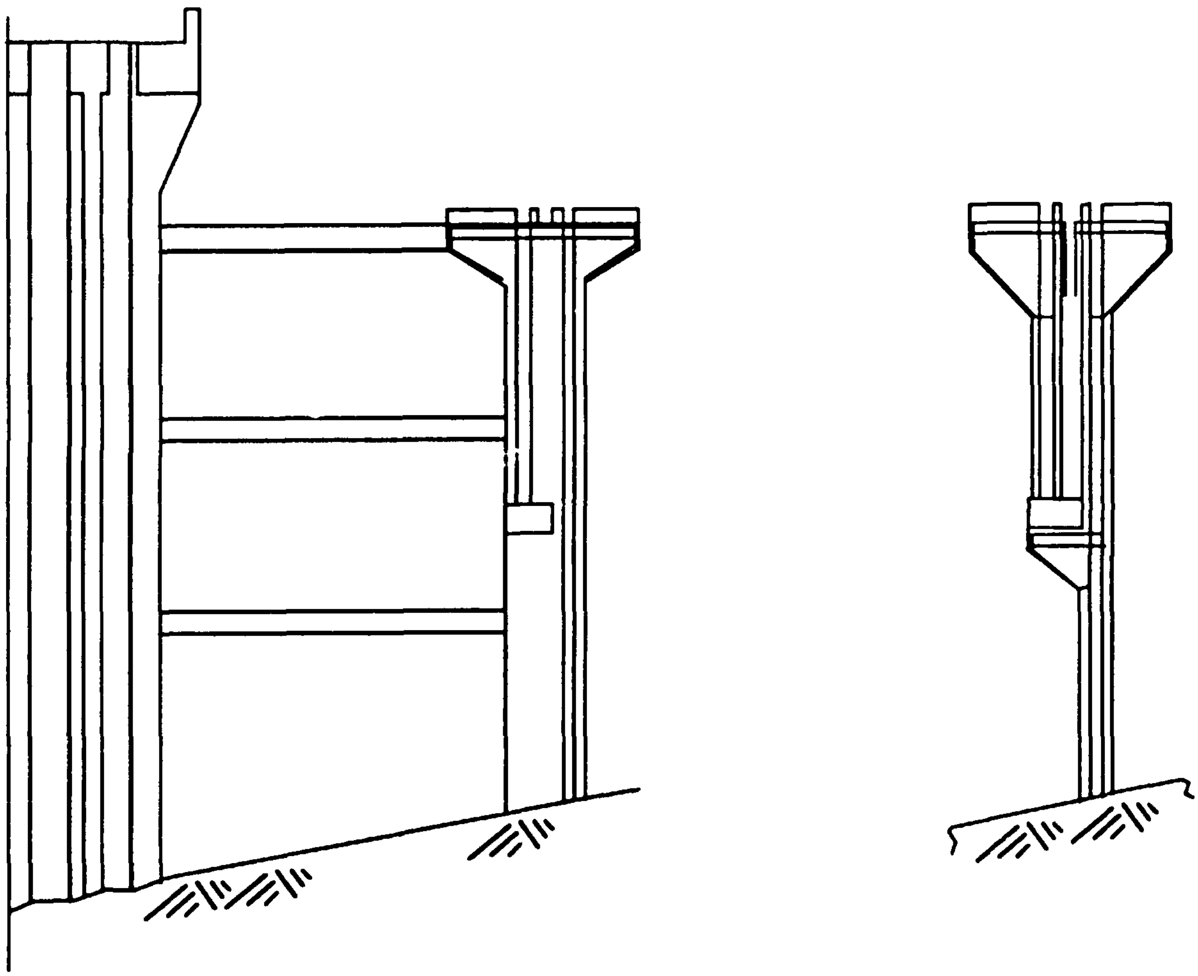


Figure 117. Schematic diagram of the FPS

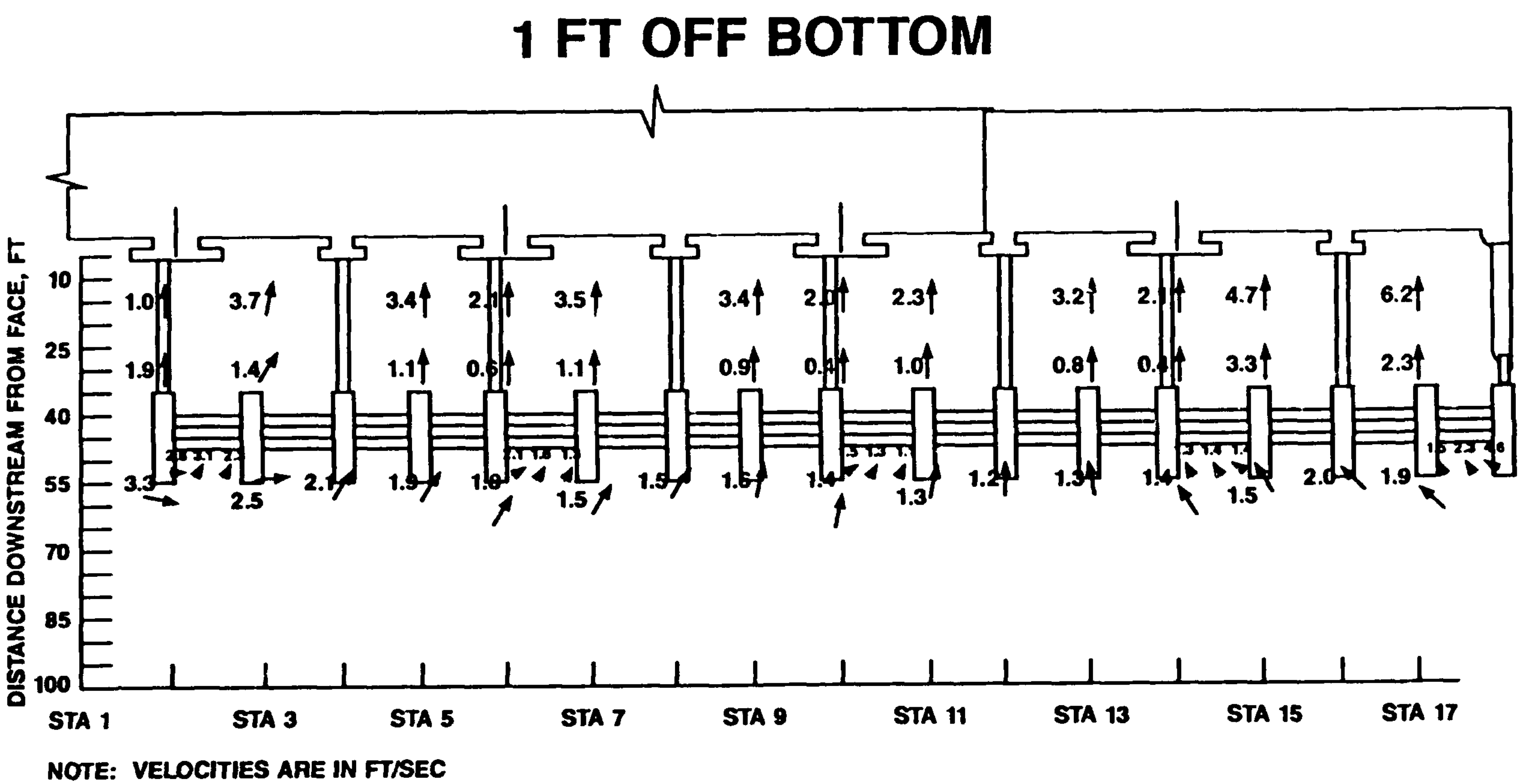


Figure 118. Velocities measured 1 ft off the bottom at various distances downstream from the face of the dam, with all four units operating, a tailrace water-surface elevation of 330, and the FPS installed

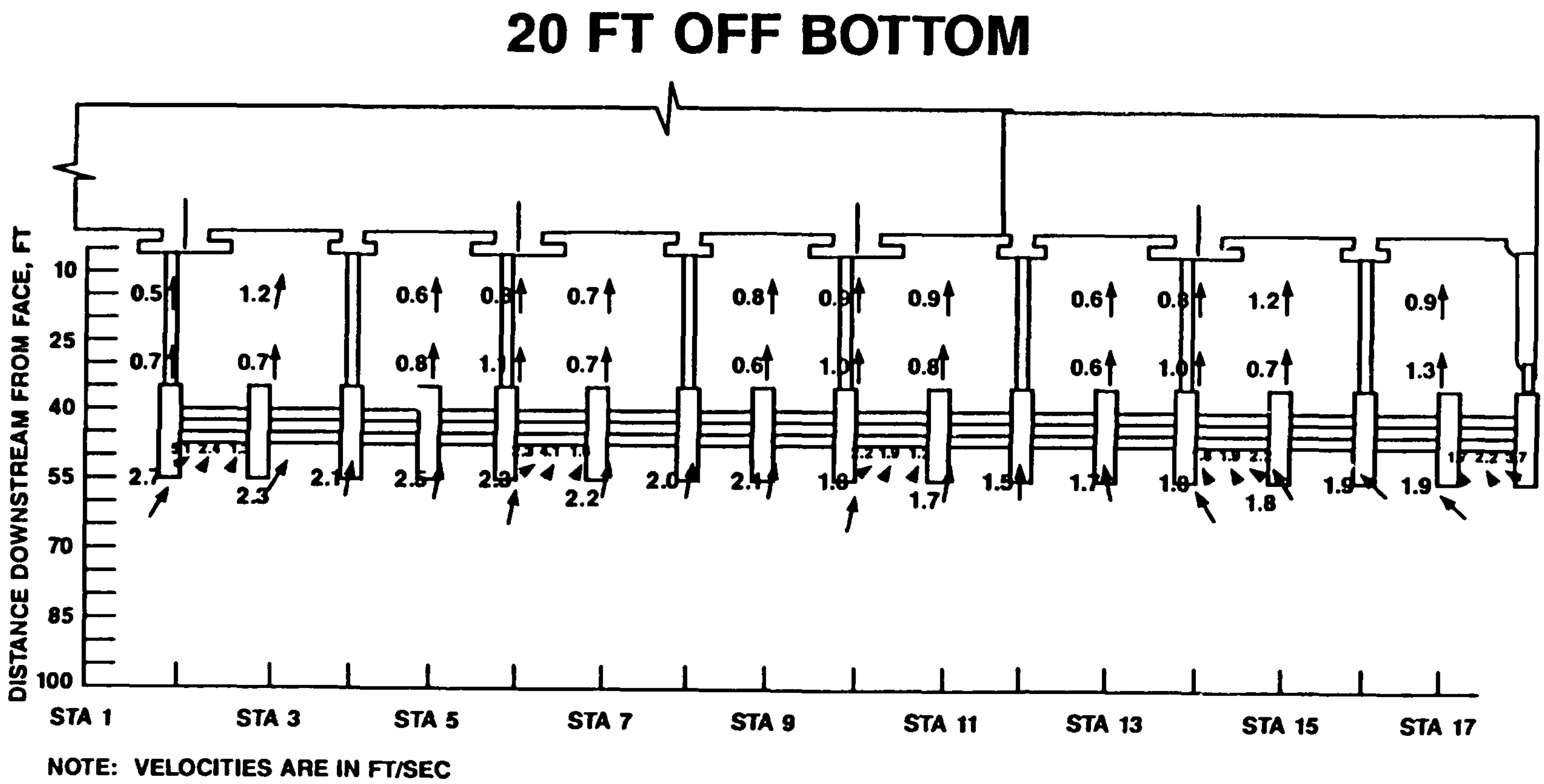


Figure 119. Velocities measured 20 ft off the bottom at various distances downstream from the face of the dam, with all four units operating, a tailrace water-surface elevation of 330, and the FPS installed

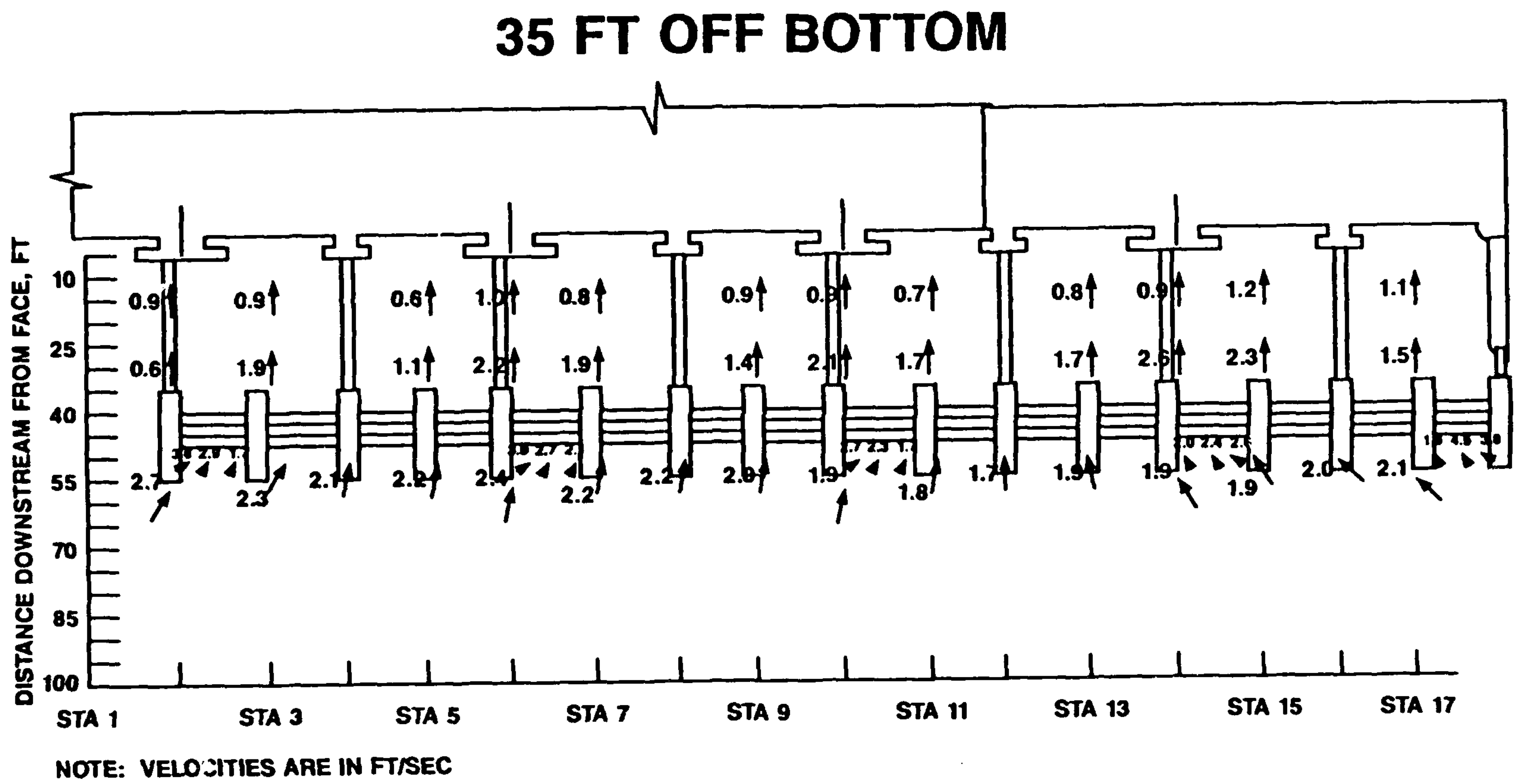


Figure 120. Velocities measured 35 ft off the bottom at various distances downstream from the face of the dam, with all four units operating, a tailrace water-surface elevation of 330, and the FPS installed

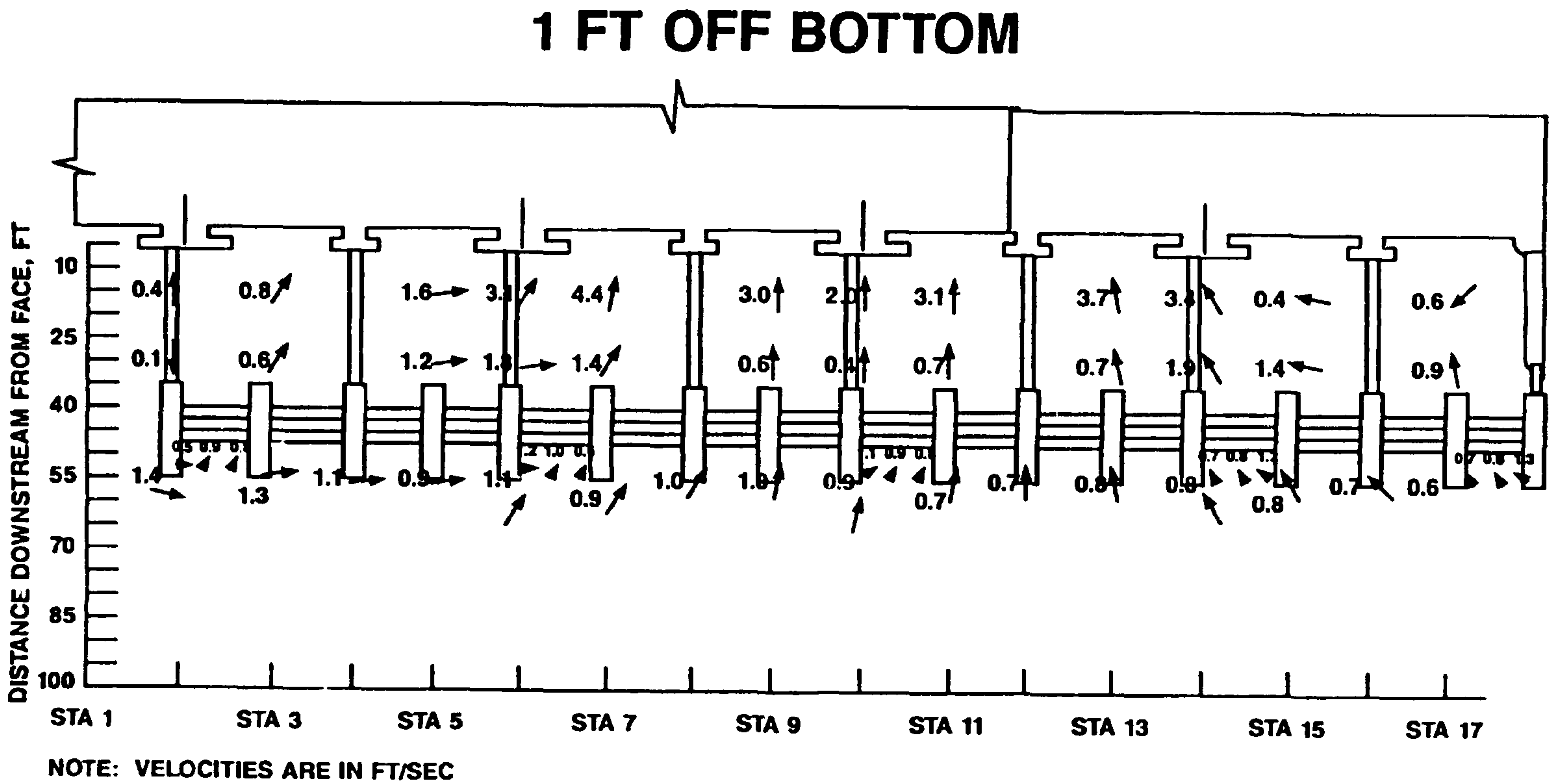
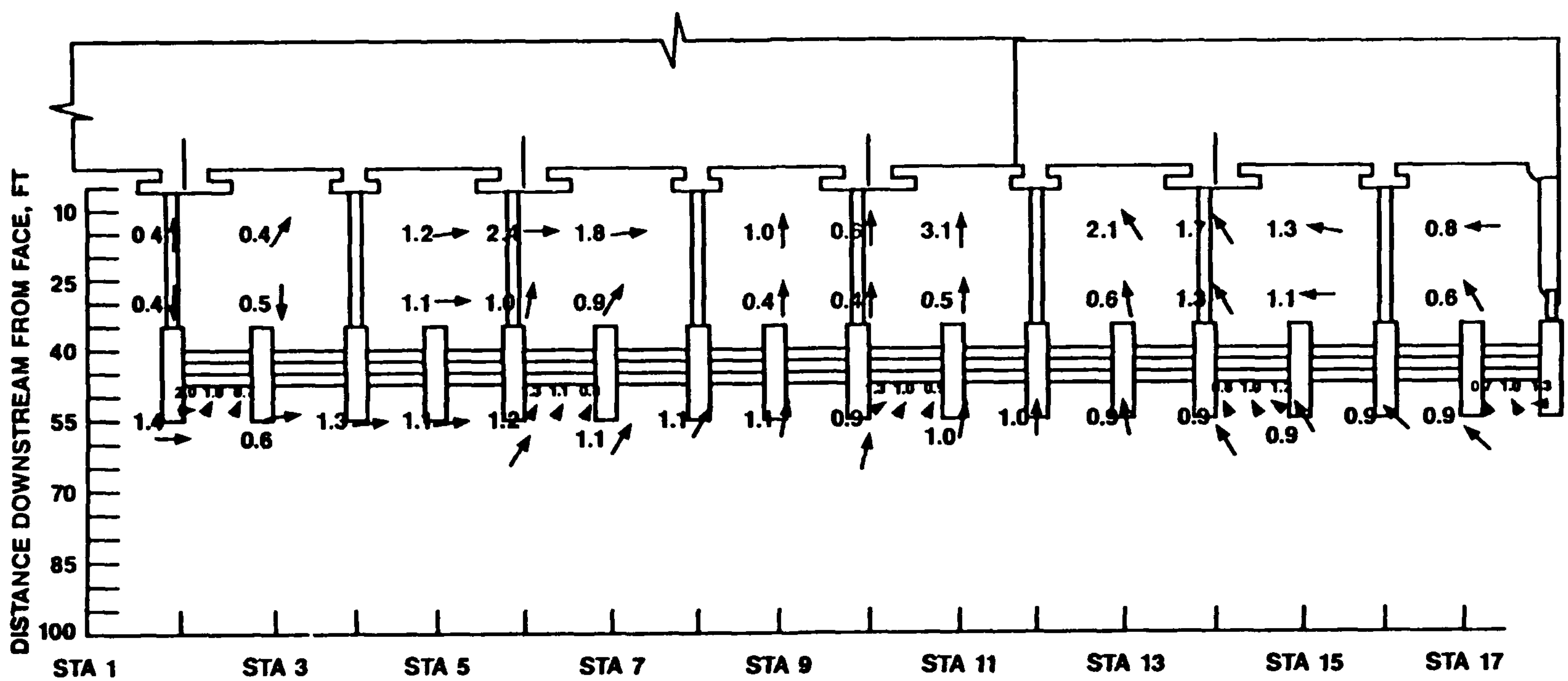


Figure 121. Velocities measured 1 ft off the bottom at various distances downstream from the face of the dam, with Units 6 and 7 operating, a tailrace water-surface elevation of 330, and the FPS installed

20 FT OFF BOTTOM



NOTE: VELOCITIES ARE IN FT/SEC

Figure 122. Velocities measured 20 ft off the bottom at various distances downstream from the face of the dam, with Units 6 and 7 operating, a tailrace water-surface elevation of 330, and the FPS installed

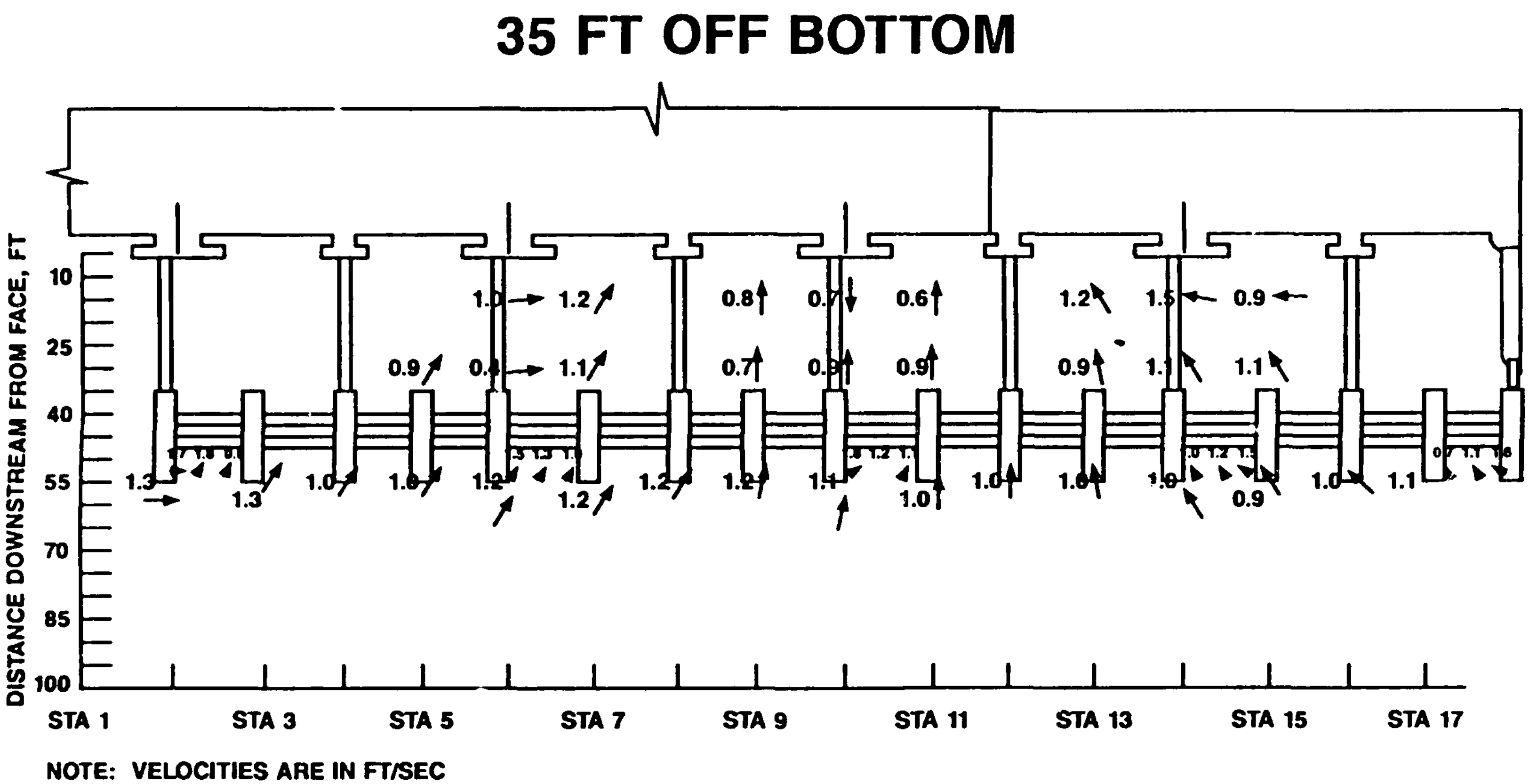


Figure 123. Velocities measured 35 ft off the bottom at various distances downstream from the face of the dam, with Units 6 and 7 operating, a tailrace water-surface elevation of 330, and the FPS installed

UNITS OPERATING					AVG. VEL. FOR MIDDLE 50% OF BAR RACK	
5	6	7	8	TRWSEL	CLOGGED	CLEAN
X	X	X	X	330	3.1	2.5
X	X	X	X	320	3.2	2.6
	X	X		330	1.7	1.1
	X	X		320	1.8	1.3
X	X	X		330	1.7	1.7
X	X	X		320	2.6	2.0

Figure 124. Average velocities for the middle 50 percent of the west bar rack when clogged and cleaned, under a variety of operating situations

UNITS 5-8 OPERATING
TRWSEL - 330

- MAX VELOCITY, FT/SEC
  - ORIGINAL DESIGN 4.1
  - BAR RACK ADDED TO UNIT 4 2.0
- AVG. VELOCITY, FT/SEC
  - ORIGINAL DESIGN 2.6
  - BAR RACK ADDED TO UNIT 4 1.5

Figure 125. Comparison of maximum and average approach velocities to left bar rack of Unit 5 with and without a bar rack added to Unit 4

UNITS OPERATING 5	6	7	8	TRWSEL	AVERAGE APPROACH VELOCITY FT/SEC	DISTANCE FROM POWERHOUSE
X	X	X	X	330	1.7	40 FT
X	X	X	X	330	1.3	50 FT
X	X	X	X	320	2.0	40 FT
X	X	X	X	320	1.9	50 FT

Figure 126. Average approach velocities 40 and 50 ft from the powerhouse, with Units 5-8 operating, tailrace water-surface elevation of 320 and 330 ft, and no FPS

UNITS OPERATING 5	6	7	8	TRWSEL	AVERAGE APPROACH VELOCITY, FT/SEC
X	X	X	X	330	2.3
X	X	X	X	320	2.6
X	X	X	X	312	3.3
	X	X		330	1.1
	X	X		320	1.3
	X	X		312	2.0
X	X	X		330	1.8
X	X	X		320	1.9
X	X	X		312	2.6

Figure 127. Average approach velocities with various combinations of units operating, three water-surface elevations, and the FPS installed

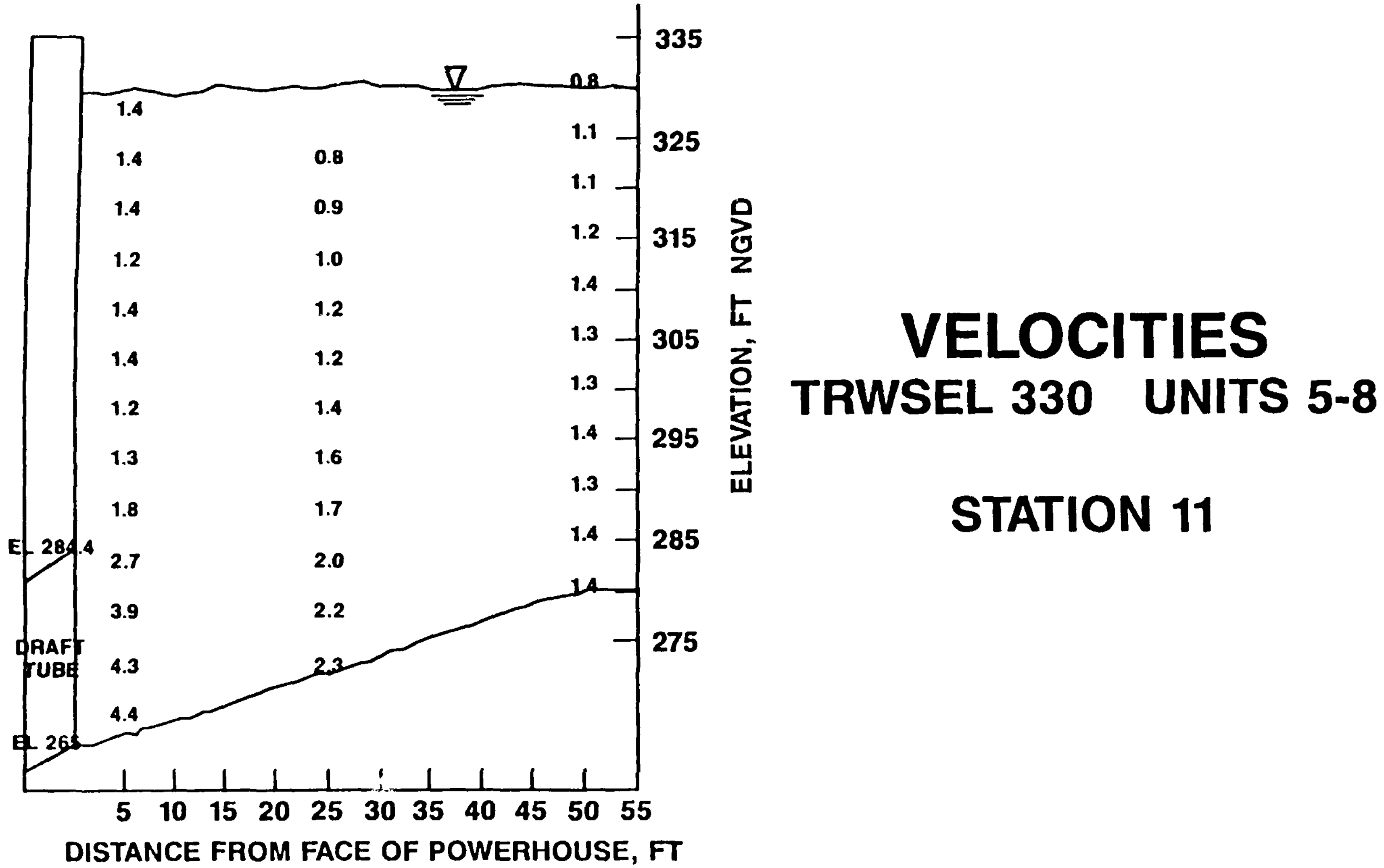


Figure 128. Velocities at various distances from the powerhouse at Station 11 with Units 5-8 operating, a tailrace water-surface elevation of 330, and no FPS

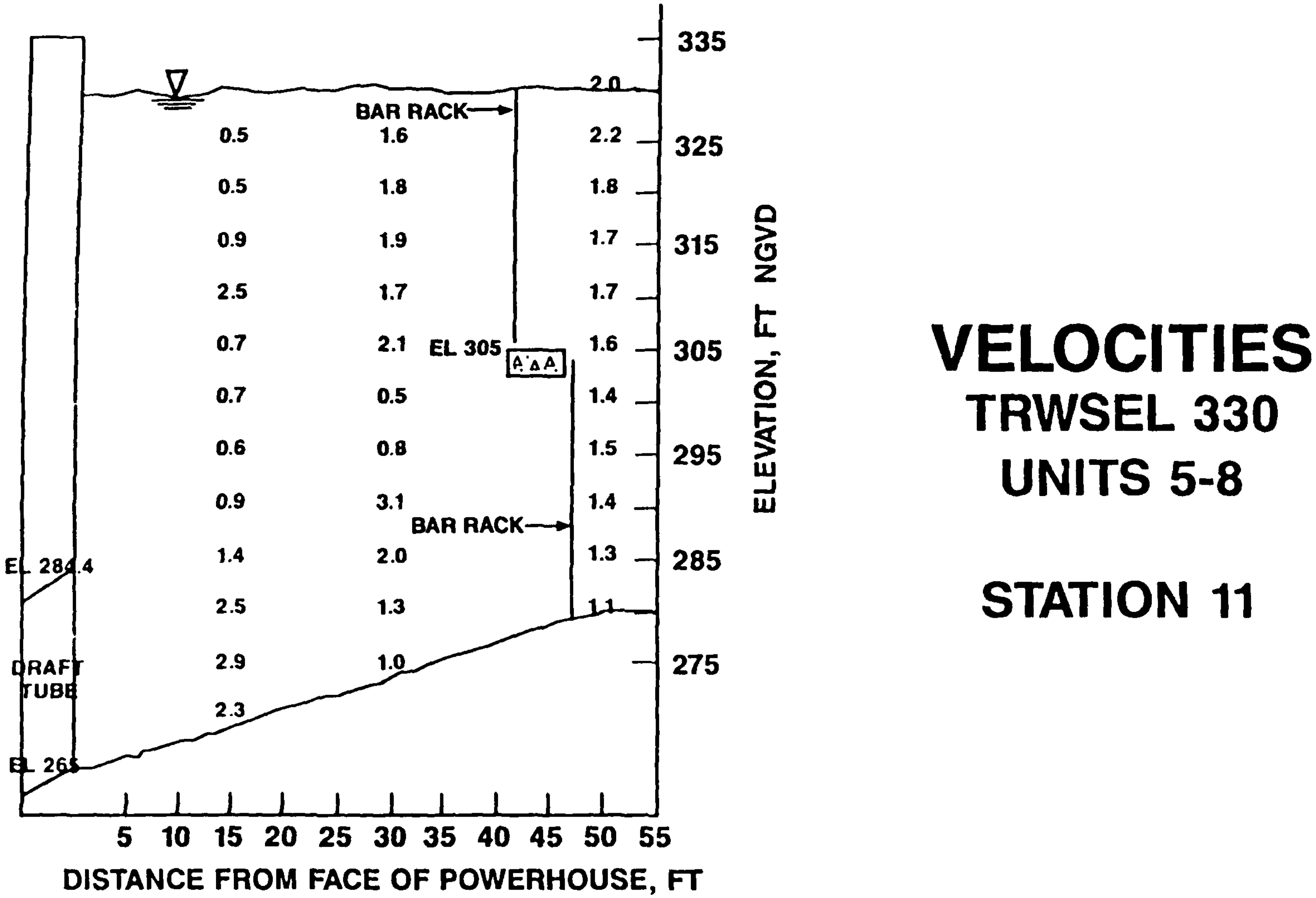


Figure 129. Velocities at various distances from the powerhouse at Station 11 with Units 5-8 operating, a tailrace water-surface elevation of 330, and the FPS installed

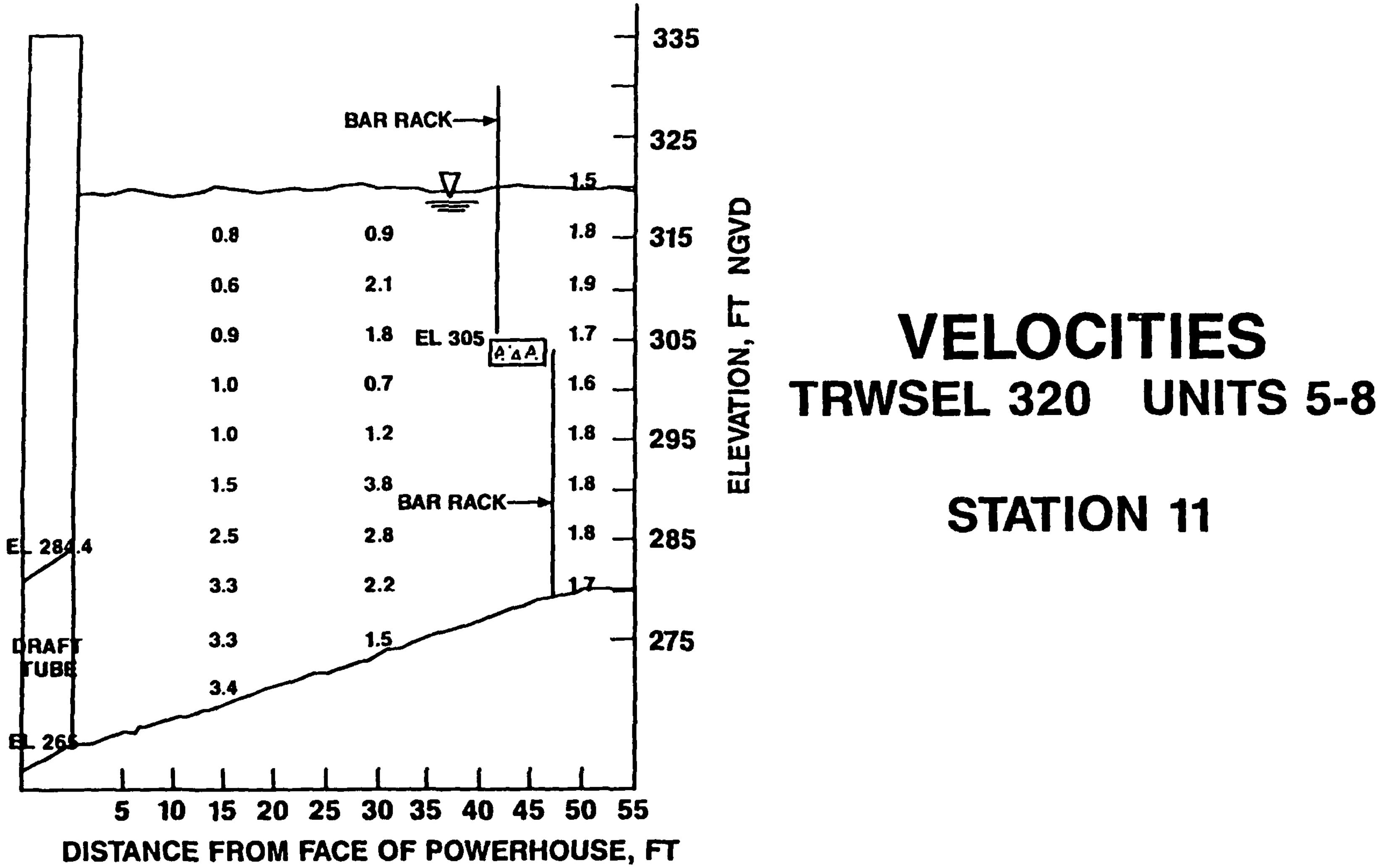


Figure 130. Velocities at various distances from the powerhouse at Station 11 with Units 5-8 operating, a tailrace water surface elevation of 320, and the FPS installed

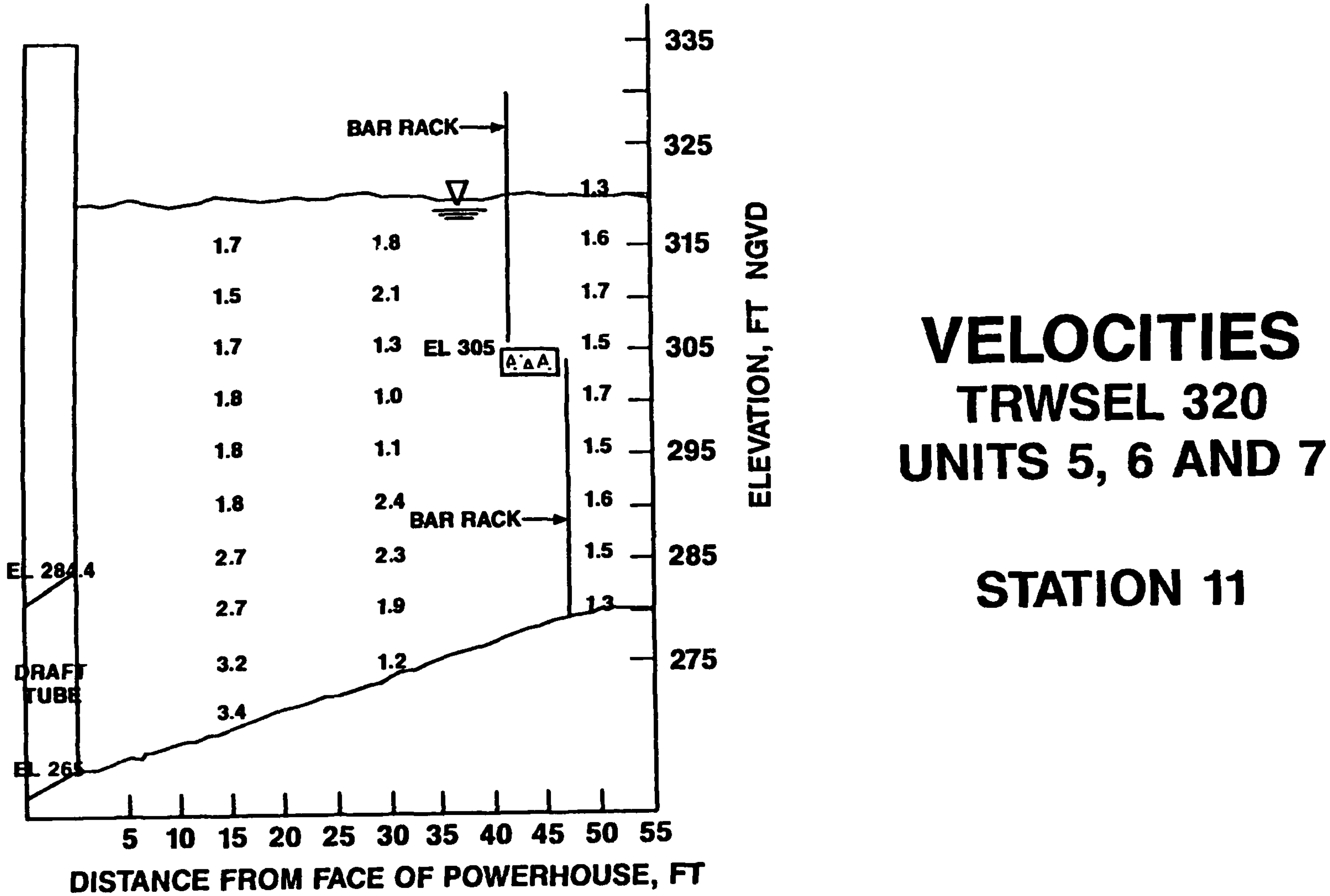


Figure 131. Velocities at various distances from the powerhouse at Station 11 with Units 5-7 operating, a tailrace water surface elevation of 320, and the FPS installed

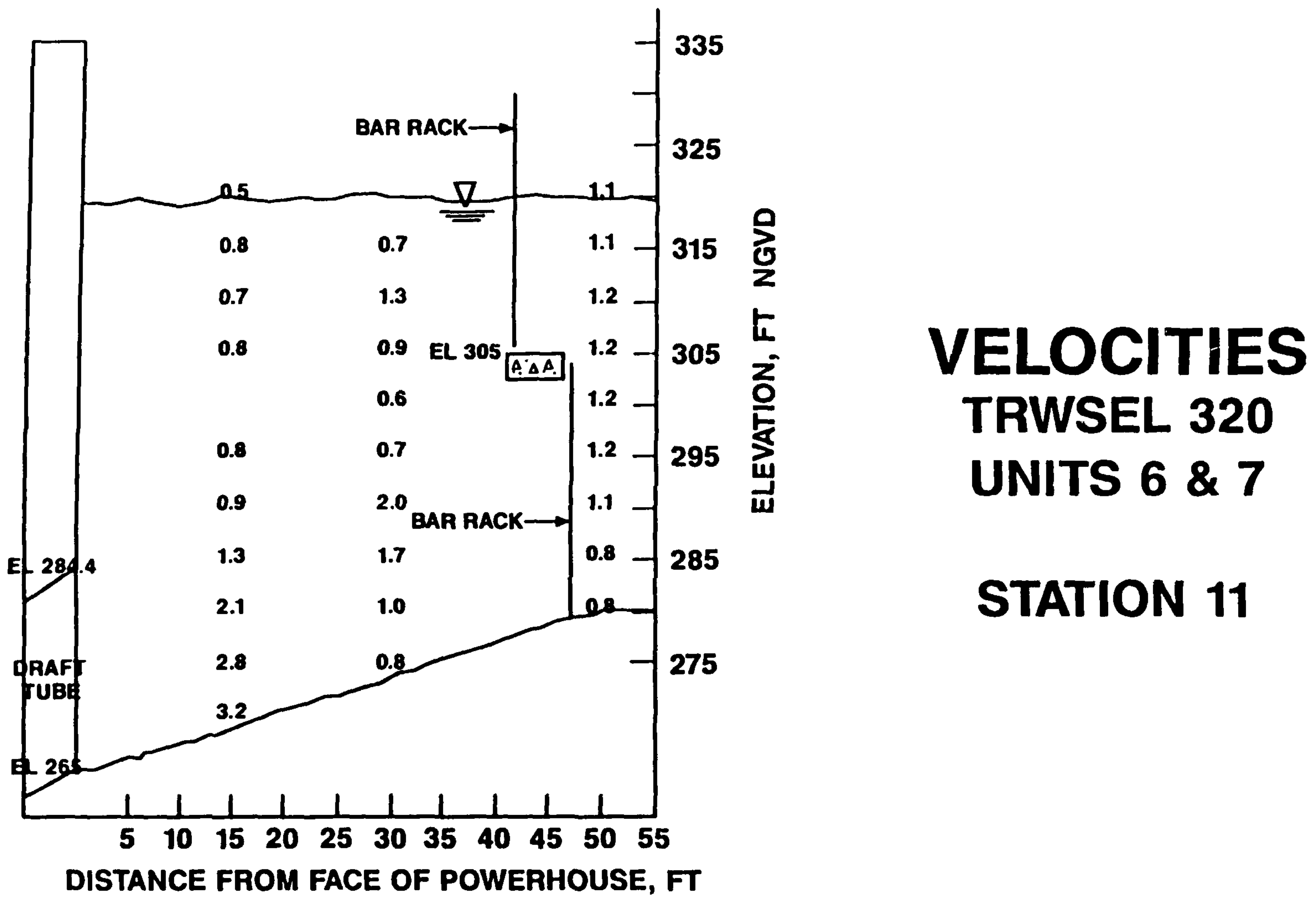


Figure 132. Velocities at various distances from the powerhouse at Station 11 with Units 6 and 7 operating, a tailrace water surface elevation of 320, and the FPS installed

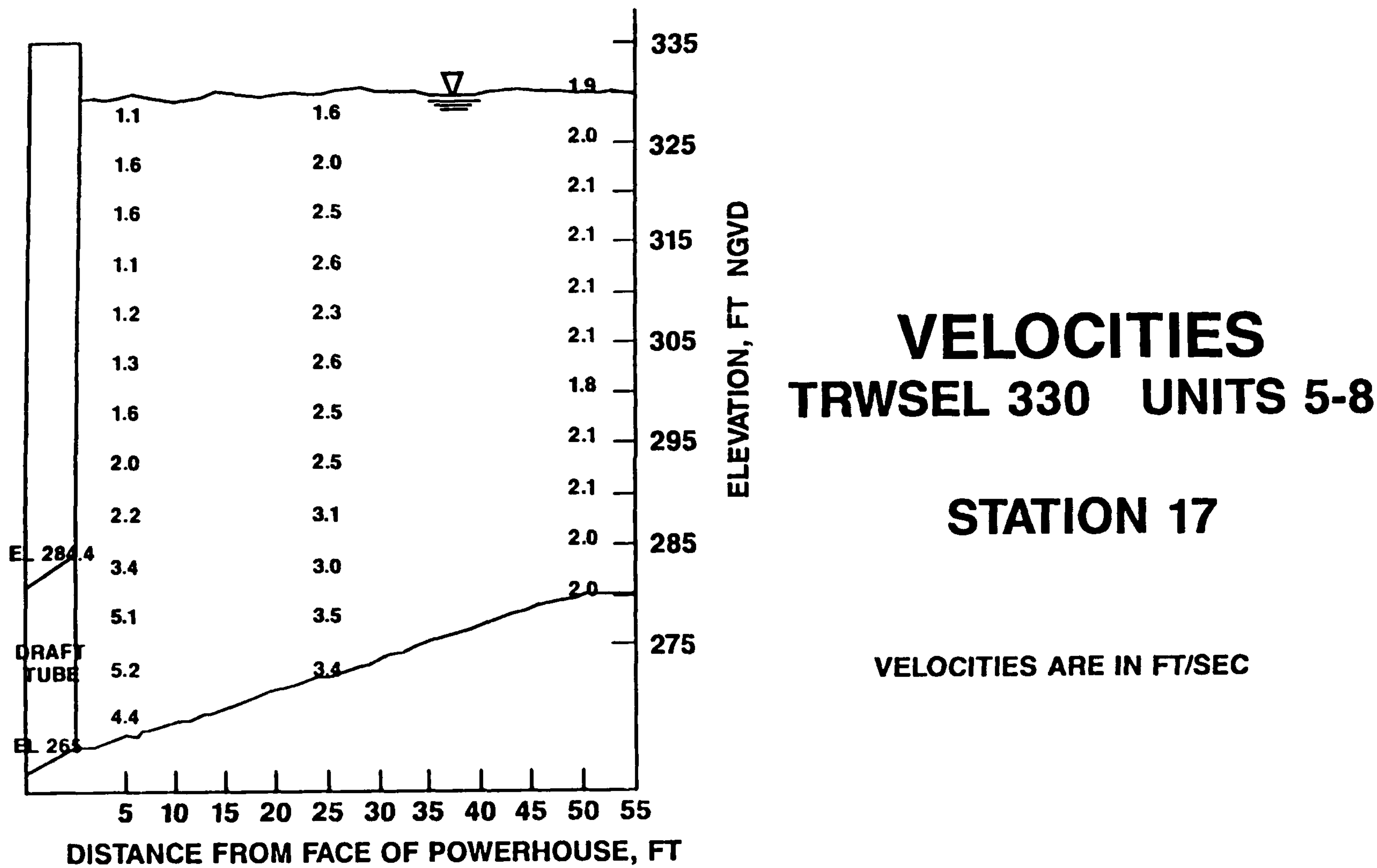


Figure 133. Velocities at various distances from the powerhouse at Station 17 with Units 5-8 operating, and a tailrace water surface elevation of 330

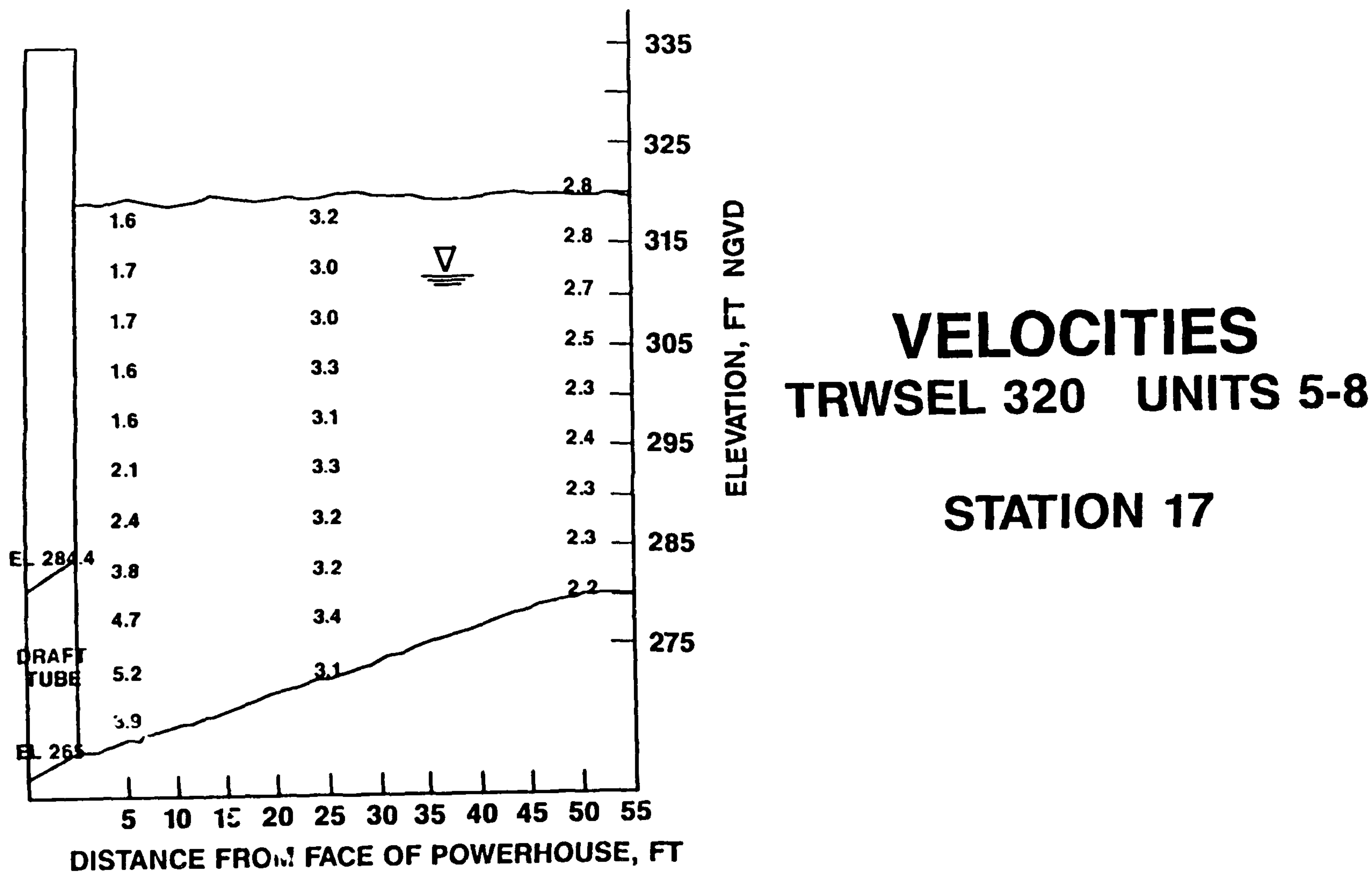


Figure 134. Velocities at various distances from the powerhouse at Station 17 with Units 5-8 operating, and a tailrace water surface elevation of 320

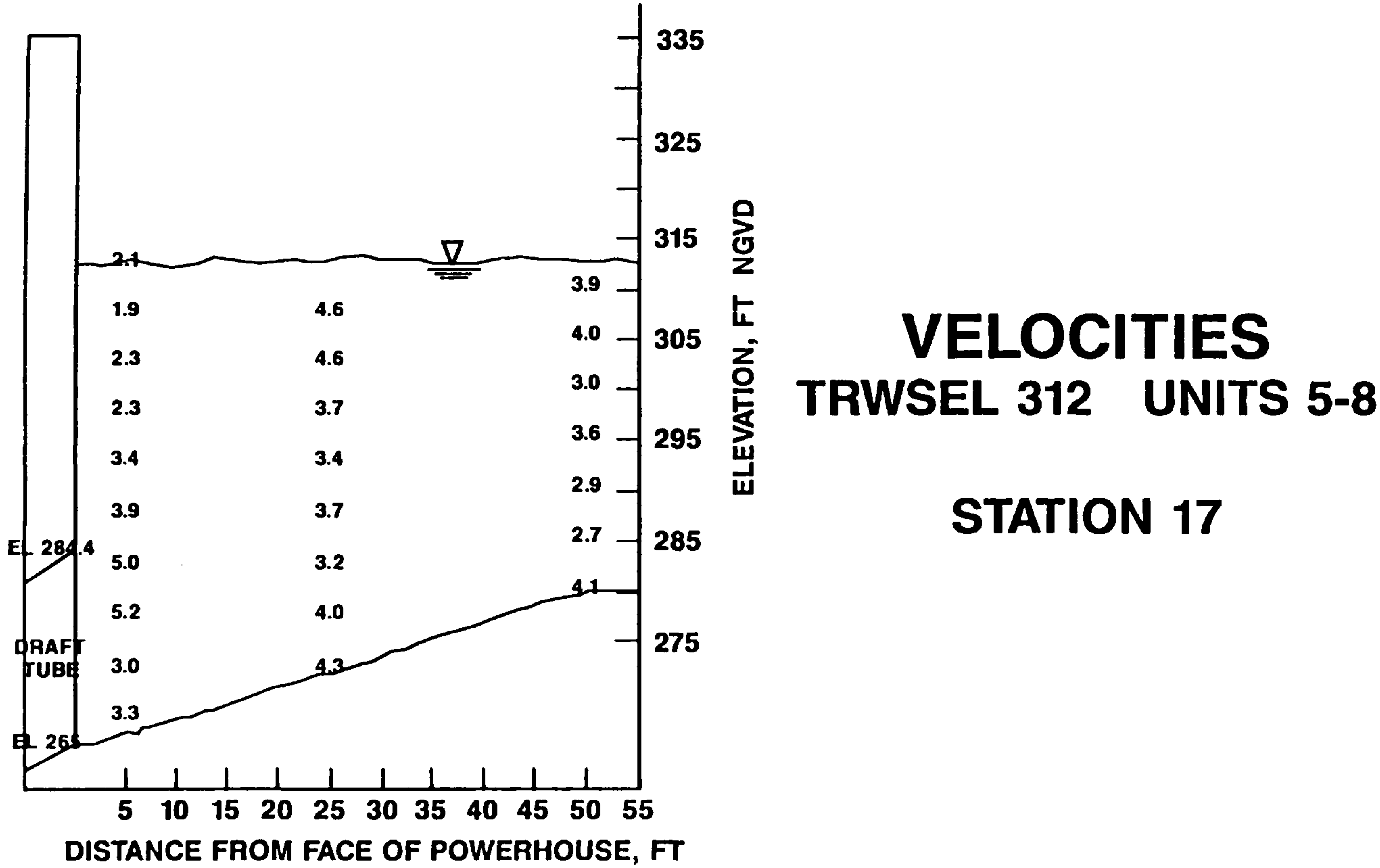


Figure 135. Velocities at various distances from the powerhouse at Station 17 with Units 5-8 operating, and a tailrace water surface elevation of 312

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